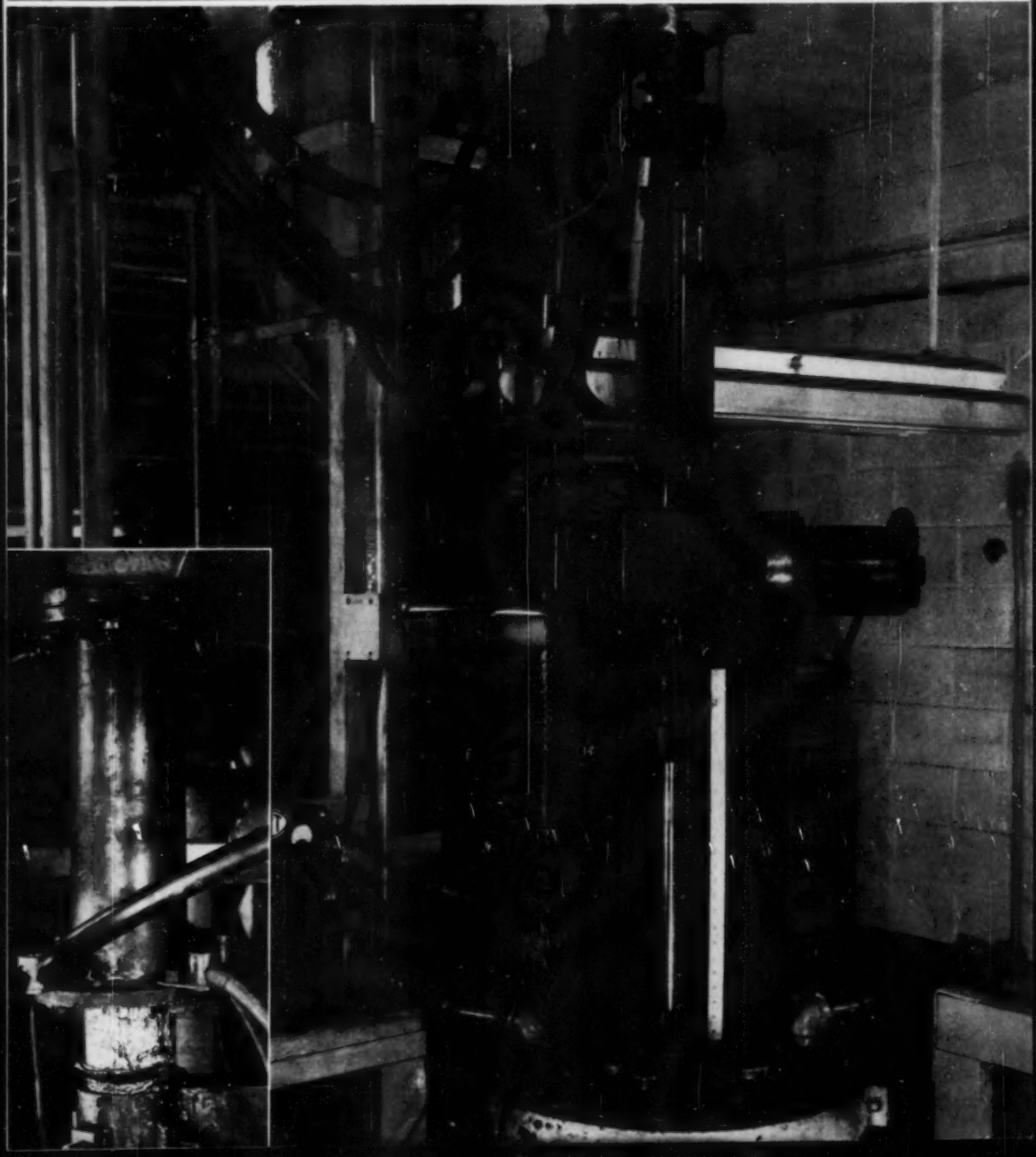
JUNE, 1951
IN TWO SECTIONS—SECTION ONE

Journal of METALS



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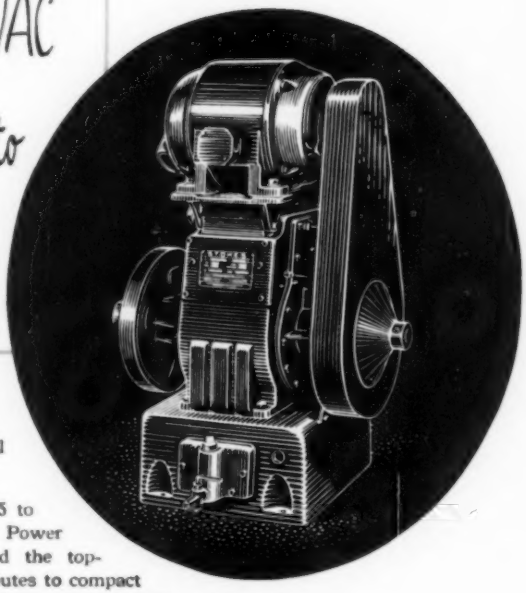

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Journal of **METALS**

VOL. 3, NO. 6 — JUNE, 1951

IN TWO SECTIONS — SECTION ONE

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COVER

Single-electrode arc-melting furnace used for the continuous casting of titanium designed and built by duPont. Inset shows titanium ingot being withdrawn from the mold.

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Short Cuts . . .

Rem-Cru Titanium, Inc. has centered sales and research activities on titanium at Midland, Pa. Production facilities are being installed in the Midland Works of Crucible Steel, and a new melting furnace for titanium was recently placed in operation. The company is jointly owned by Remington Arms, Inc., and Crucible Steel Co. of America.

Baldwin-Lima-Hamilton Corp., Eddystone, Pa., and Fairbanks, Morse & Co., Chicago, Ill. were awarded contracts for 16 diesel-electric locomotives for use at U.S. Steel's Fairless Works. Diesel locomotives will be used in keeping with the policy of smoke abatement wherever possible at the new mill.

Aluminum Co. of America will build an aluminum smelting plant at Wenatchee, Wash., with a 170 million lb annual capacity. Standby production facilities at Massena, N. Y., and Badin, N. C., uneconomical for normal operation because of high power cost, have been reactivated to provide 158 million lb of aluminum annually for the Government stockpile.

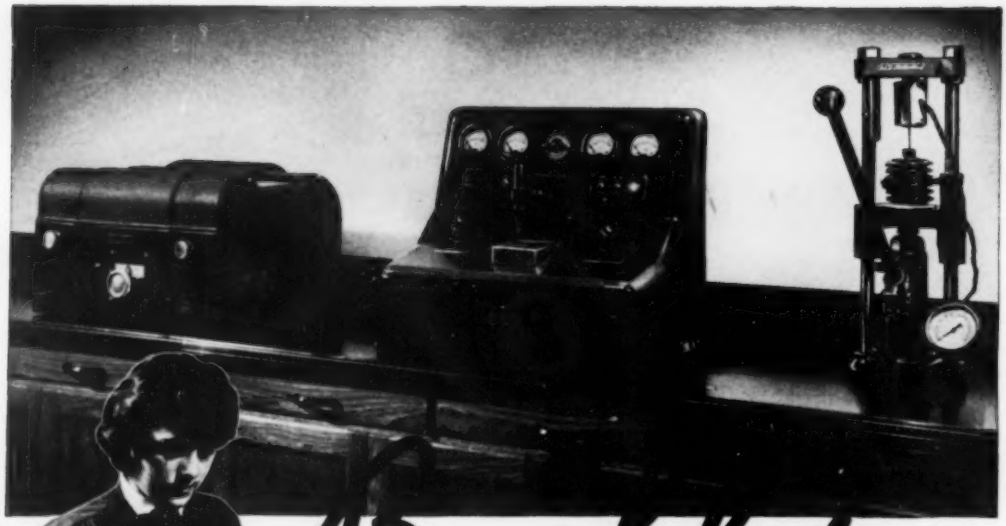
Mesta Machine Co., Pittsburgh, will build an 80-in. continuous hot strip mill for Fairless Works, U.S. Steel. The mill, which will roll slabs from 4 to 8 in. thick and 8 to 20 ft long into steel coils 640 to 3200 ft long in one continuous operation, will be about 1/3 mile long. Sheets up to 72 in. wide and 0.1 in. thick will be the hot mill end product.

Rust Furnace Co., Pittsburgh, will design and supply four continuous slab heating furnaces for Fairless Works. The furnaces, of the zone-controlled, triple-fired, recuperative type, will have full automatic temperature and furnace pressure controls, and will deliver 135 tons of slabs per hr at 2250°F. Each furnace will have an inside width of 22 ft and a length of 90 ft.

Electronic Core Subcommittee of the Metal Powder Assn. has prepared standards covering all types of electronic cores made from iron powder. Standard 11-51T is available for 25c per copy from the Metal Powder Assn., 420 Lexington Ave., New York 17.

Westinghouse Electric Corp., South Philadelphia, has sold the largest gas turbine-generator yet ordered to the Public Service Co. of Oklahoma. The 15,000 kw machine will operate at 1350°F, and the installation will weigh 700,000 lb.

Iron ore imports in 1950 set a record total of 9.2 million tons. Of the 15 exporting countries Chile ranked first.



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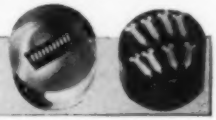

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THE following employment items are made available to AIME members on a non-profit basis by the Engineering Societies Personnel Service, Inc., operating in cooperation with the Four Founder Societies. Local offices of the Personnel Service are at 8 W. 40th St., **New York 18;** 100 Farnsworth Ave., **Detroit;** 57 Post St., **San Francisco;** 84 E. Randolph St., **Chicago 1.** Applicants should address all mail to the proper key numbers in care of the New York office and include 6c in stamps for forwarding and returning application. The applicant agrees, if placed in a position by means of the Service, to pay the placement fee listed by the Service. AIME members may secure a weekly bulletin of positions available for $3.50 a quarter, $12 a year.

POSITIONS OPEN

Metallurgical Engineer with several years' experience in ore concentration. Work to be mill operation and some development. Expanding organization. Salary, to $6000 a year. Location, Southeast. Y5405

Works Manager, metallurgical or mechanical graduate, with at least 5 years' ferrous and aluminum alloy powder metallurgy experience, to supervise operations of small plant. Salary open. Location, upstate New York. Y5393

Junior Metallurgist to do metallography and research in field of powder metallurgy. Salary, $3380 to $3900 a year. Location, Westchester County, N. Y. Y5353

Metallurgist, to develop welding procedures for improvement in quality and reduction in cost. Specify welding equipment and techniques for use in production of products involving carbon and alloy steel in cast or rolled form. Advise product engineers as to materials for design of products for best application of welding. Supervise qualification testing of welding processes and welding operators. Supervise X-ray equipment and X-ray operators. Perform metallurgical tests as required, interpret test results and reports, and recommend any steps to be taken based on such tests. Location, New York State. Y5329(b)

Lubrication Sales Engineer, 32 to 40, with experience in sales of industrial and automotive lubricants, to sell lubricating oils and greases throughout Latin America. Considerable traveling. Must have knowledge of Spanish. Salary, $7200 a year plus expenses. Y5204

Metallurgist, graduate, preferably one with some experience in electric furnace melting. Some experience in melting of alloy, high speed, tool and stainless steels desirable. Salary open. Location, Pennsylvania. Y5203

Metallurgist for new nonferrous smelter in Chicago area. Write stating full particulars. Y5057C

Metallurgist experienced in physical and process ferrous metallurgy, to engage in contact and development work regarding alloy steels. Location, Pittsburgh. Y4981

Metallurgical Engineer to instruct courses in mineral preparation, concentration and leaching, plant design and graduate courses. Should be interested in research. Prefer man with advanced degrees and some experience. Write stating full personal particulars, education, details of experience and references. Position will start September. S967

Metallurgical Engineer, graduate with 1 or 2 years' experience in development laboratory handling customer products. Must have knowledge of heat treating. Work will involve tending furnace, layout work, set-up metallurgical laboratory for analysis, variations, fluctuations. Might eventually lead to management work. Salary open. Location, northern Indiana. T7668

Engineers (a) Mill Superintendent with minimum of 5 to 10 years' experience in the operation of a mill for metal mining company. (b) Assistant Mining Engineers for metal mining operations in the Philippine Islands. Salaries open. Y5022

Superintendent to take charge of a mine and mill at copper, silver, and gold property. Salary open. Montana. Y4975

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Senior Research and Development Metallurgist seeks opportunity to expand responsibility. Prepared to supervise metallurgical section, act as asst. to director of research large company or full responsibility in smaller one. Background includes success in research, development, and production in powder metallurgy, refractory metals, aircraft, welding industries. Go anywhere for right job. M-623

Mineral Economist, 28, married, B.S. mineral economics and geology, Penn State College; M.A. resources and economics, University of Texas. Experienced coal mining, concentrating plants and manufacturing of copper products. Desires responsible position mining or iron and steel industry in sales engineering or other specialized work relating to this field. M-624

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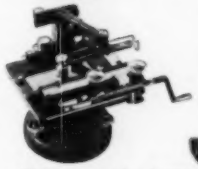

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2—MERCURY CLEANER: Up to 600 lb of mercury per day can be cleaned of dissolved base metals and floating impurities such as water, oil, and dust, with *Bethlehem Apparatus Co.'s* 150 lb capacity mercury oxifier and filter. Residual contamination is less than one ppm, and the cleaned mercury can be used in precision instruments and wherever high purity is desirable.

3—DUAL-PURPOSE OIL: A combination bearing lubricant and roll oil is marketed by the *Texas Co.* to meet the demands of the Sendzimir Precision cold strip rolling mill. It permits proper lubrication of the antifriction bearings, acts as a coolant on the strip during rolling, provides rust protection during shutdowns, and is easily removable.

4—STRIP-CHART RECORDER: *Baldwin-Lima-Hamilton Corp.* offers a self-contained, portable recorder for plotting automatically on rectangular coordinates the simultaneous relationship between any two variables that can be made to actuate the variable transformers. It can also be used with any testing machine in which hydrostatic pressure in the loading or weighing system is proportional to load applied to the specimen, and some types of testing machines having mechanical loading and weighing systems.

5—ADHESIVES: Four industrial adhesives in liquid, powder and rod form that can be cured at room or elevated temperatures are produced by *Houghton Laboratories, Inc.* Liquid Adhesive 101 is recommended for bonding metal to metal, glass to glass, ceramics to ceramics, and hard rubber to glass, metal, or wood; Liquid Adhesive 102 is intended for use where one of the parts is porous, such as bonding metal to plywood; Solid Type I is used where optimum shear strength is desired; and Liquid Type XV is a liquid version of solid type I.

6—MAGNETIC HOLDER: A magnetic-base indicator holder, announced by *Enco Mfg. Co.*, attaches to flat or curved surfaces with 100 lb pull to hold all types of dial indicators in operating position.

7—TACHOMETER: U.S. Varidrive motors are now available with a variable speed electric tachometers for applications that require continuous and accurate speed indication. *U.S. Electrical Motors, Inc.*

8—SILVER-CLAD STEEL: Steel strip clad on one or both sides with solid sheet silver is available from *American Silver Co., Inc.*, in widths up to 4 in. and thicknesses down to 0.005 in. It can be shaped by stamping, bending, drawing and spinning.

9—CONTACT WHEEL: A new type of contact wheel for abrasive belt application on backstand idler applications is now produced by the *Carborundum Co.* The specially-serrated rubber wheel reduces glazing and doubles belt life.

10—WELDING FLUX: A cast iron welding flux in the form of finely ground powder is said to have good cleaning action, and impart superior flow characteristics to cast iron welding rods. *All-State Welding Alloys Co. Inc.*

11—POWDER METAL PRESSES: Hydraulic presses for pressing and coining powder metal parts are now being manufactured by *Arthur Colton Co.* These presses, offering economy and precision, are based on original developments of the company.

12—RUST INHIBITOR: Ferrous metals that must be immersed in or contain water are prevented from rusting by the addition of Immunol, a liquid chemical, to the water. Immunol will not affect the skin, and is said to replace alkali cleaners and inflammable solvents. *Haas Miller Corp.*

13—OINTMENT FOR BURNS: A-Gic, a gel prepared from the Aloe Leaf, reported to be effective in treating X-ray burns as well as fire, acid, alkali, and industrial burns, is marketed by *Cargille Scientific Inc.*

14—RADIATION DOSEMETER: The SU-8 Pocket Dosemeter is designed by *Tracerlab* to provide scientists and technicians handling radioactive material with a quick and accurate indication of the amount of radiation exposure during a given period of time.

15—GRAPHITE ANODE: A new size 3x60 in. graphite ground anode provides longer life, is rugged, and is easy to transport to the field. The anodes are recommended for the cathodic protection of pipe lines, tanks, and all sorts of underground and underwater metal structures. *National Carbon Co.*

Journal of Metals **June**
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16—NICKEL BRIGHTENER: The Smoothex Brightener Process, using new organic addition agents, provides a fast, low cost, lustrous nickel plating method. Developed by *The Gill Corp.*, the process can be operated at current densities of 50 to 100 amp per sq ft.

17—RED LEAD: Red lead in an alkyd resin vehicle is formulated by *John W. Masury & Sons, Inc.* to meet demands of steel fabricators for a shop coat. It gives good protection without a finish coat, and can be brushed or sprayed.

18—REFRIGERATION: Reciprocating refrigeration machines designed for air conditioning and refrigeration use in the 100 to 150 hp range are announced by *Carrier Corp.* The machines are adaptable to industrial requirements such as direct product cooling, brine chilling, and ammonia and chlorine condensing.

19—ELECTRICAL STEEL: An iron-silicon alloy with a high degree of orientation and intended for use in wound-type transformers and reactors operating at 400 cycles, is made by *Armco Steel Corp.* TRAN-COR T-O-S has a minimum permeability of 1800 at 18 kilogausses, and has good workability.

Free Literature

21—VACUUM CALCULATOR: The Stokes Vacuum Calculator, a slide rule designed for quick calculations in vacuum research and processing work, is available from *F. J. Stokes Machine Co.* Pump capacities required for evacuation, water vapor-pressure, and boiling points of various solvents under pressure can be determined with the slide rule.

22—SOLID LUBRICANTS: *Climax Molybdenum Co.* has prepared a booklet "Molybdenum Disulphide as a Lubricant," containing excerpts from technical papers for all interested in lubricants and anti-fretting materials.

23—COMBUSTON SAFEGUARD: The 32-p. catalog "Protectoglo Combustion Safeguard for Industrial Gas-Fired and Oil-Fired Burners," is a complete manual on flame failure protection for industrial applications. *Minneapolis-Honeywell Regulator Co.*

24—OPTICAL PARTS: Information on standard precision optical parts for engineers and designers is contained in *Bausch & Lomb Optical Co.'s* new catalog.

25—BALL BEARINGS: A 12-p. catalog on miniature ball bearings containing specifications and typical applications is available from *Miniature Precision Bearings, Inc.*

26—SOUND FILMS: Sound films covering general interest subjects, product information, and training and instruction courses are lised in a new catalog offered by *Westinghouse Electric Corp.*

27—CHROMIUM PLATING: The Model A-20 Chromaster, an industrial hard chromium plating unit, is described in a 4-p. bulletin of *Ward Leonard Electric Co.* The unit is compact, and has a built-in power supply.

28—METAL SPINNING: A 38-p. bulletin issued by *Spincraft, Inc.*, outlines what can be done with the combination of metal spinning and metal fabrication. Many specific applications are described in this well illustrated presentation.

29—PUMPS AND HEAT EXCHANGERS: Literature describing Nu-Kast pumps and heat exchangers designed for transfer of corrosive liquids is offered by *Nukem Products Corp.* The pumps, made of cast resins, are low priced and light weight; the heat exchangers are of Karbate.

30—TUBING STEELS: Condensed technical information concerning the design, fabrication, and use of tubing for elevated temperature and high pressure applications is contained in a 6-p. bulletin of *Babcock & Wilcox Tube Co.* Included are data on carbon, intermediate chromium-molybdenum, and stainless steels.

31—ALUMINUM PROTECTION: A folder on the protection of aluminum by Alodizing, a protective surface conversion process for bonding paint to aluminum, is obtainable from *American Chemical Paint Co.*

32—TEMPERATURE MEASUREMENT: Folder N-33-640(1), published by *Leeds & Northrup Co.*, describes equipment used for molten steel temperature measurement.

33—TORQUEMETERS: Baldwin SR-4 torquemeters, based on measurement with resistance wire strain gages are discussed in Bulletin 328 of *Baldwin-Lima-Hamilton Corp.* Specifications and tables of instrument characteristics are included.

34—HIGH TEMPERATURE TESTING: Marshall furnaces and controls for high temperature tensile, fatigue, creep and stress rupture tests are described in an illustrated folder of *L. H. Marshall Co.*

35—SPECIMEN POLISHING: *Buehler, Ltd.* describes the Diamet-Hyprez line of diamond abrasives in an informative booklet. Included is a discussion of the advantages of metallurgical specimen polishing using diamond abrasives.

36—REFRACTORIES: "Super Refractories for Heat Treatment Furnaces" is the subject of a 40-p. booklet issued by the *Carborundum Co.* A full line of refractories and their applications is described.

37—FURNACES: The complete line of electric furnaces for heat treating is described in *Hoskins Mfg. Co.'s* catalog 59-R. All furnaces are equipped with Chromel heating elements.

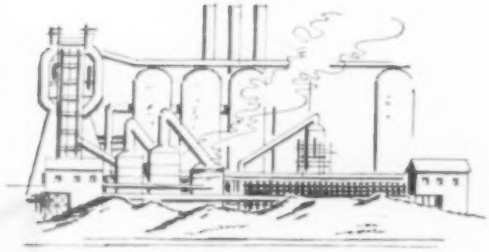
38—THREAD INSERTS: A 16-p. bulletin covering design data on helical-wire thread inserts and their use in the protection and repair of tapped holes is offered by *Heli-Coil Corp.*

39—FORCE INDICATORS: Engineering specifications on a precision instrument used for accurate force measurement in design, research, production, inspection, and maintenance is included in *Hunter Spring Co.'s* bulletin. A number of typical applications are described.

40—STAINLESS STEELS: Properties, available forms, and fabrication of two types of precipitation hardening stainless steels are published in a booklet by *Armco Steel Corp.* These steels combine good corrosion resistance with high strength and hardness.

41—DIE STEEL: "Prestem, the Hot Working Die Steel for Forging Presses and Upsetters," is a 4-p. bulletin issued by *Heppenstall Co.*

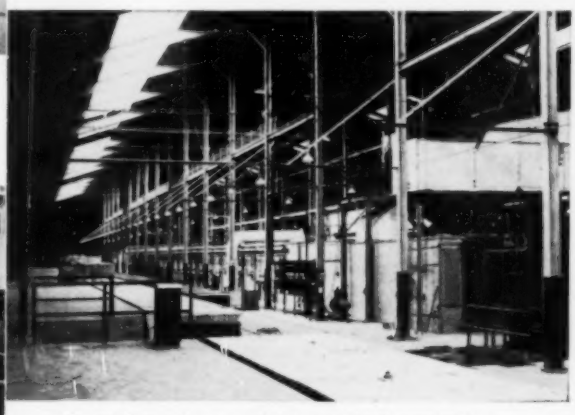
HARBISON-WALKER *Blast*



Blast furnace brick of the right quality for each zone are necessary for maximum production and greatest economy. The full complement of Harbison-Walker Blast Furnace Refractories provides for the proper selection for every combination of furnace operating conditions.

For more than half a century Harbison-Walker Blast Furnace Refractories have been the leading choice of the industry. Recent surveys disclose the fact that the major portion of linings currently installed in the United States, Canada, and Mexico are Harbison-Walker brands. At present, complete and partial Harbison-Walker linings for more than 100 blast furnaces are in process of manufacture. Whether your furnace practice calls for the best standard conventional linings or for super-duty linings, Harbison-Walker produces the refractories best suited for your specific needs.

Extensive Research is an extremely important fundamental in the development of Harbison-Walker Blast Furnace Refractories.



One of the modern tunnel kilns used in the production of blast furnace brick. Accurate control of firing conditions is a major factor in securing the most desirable physical properties.

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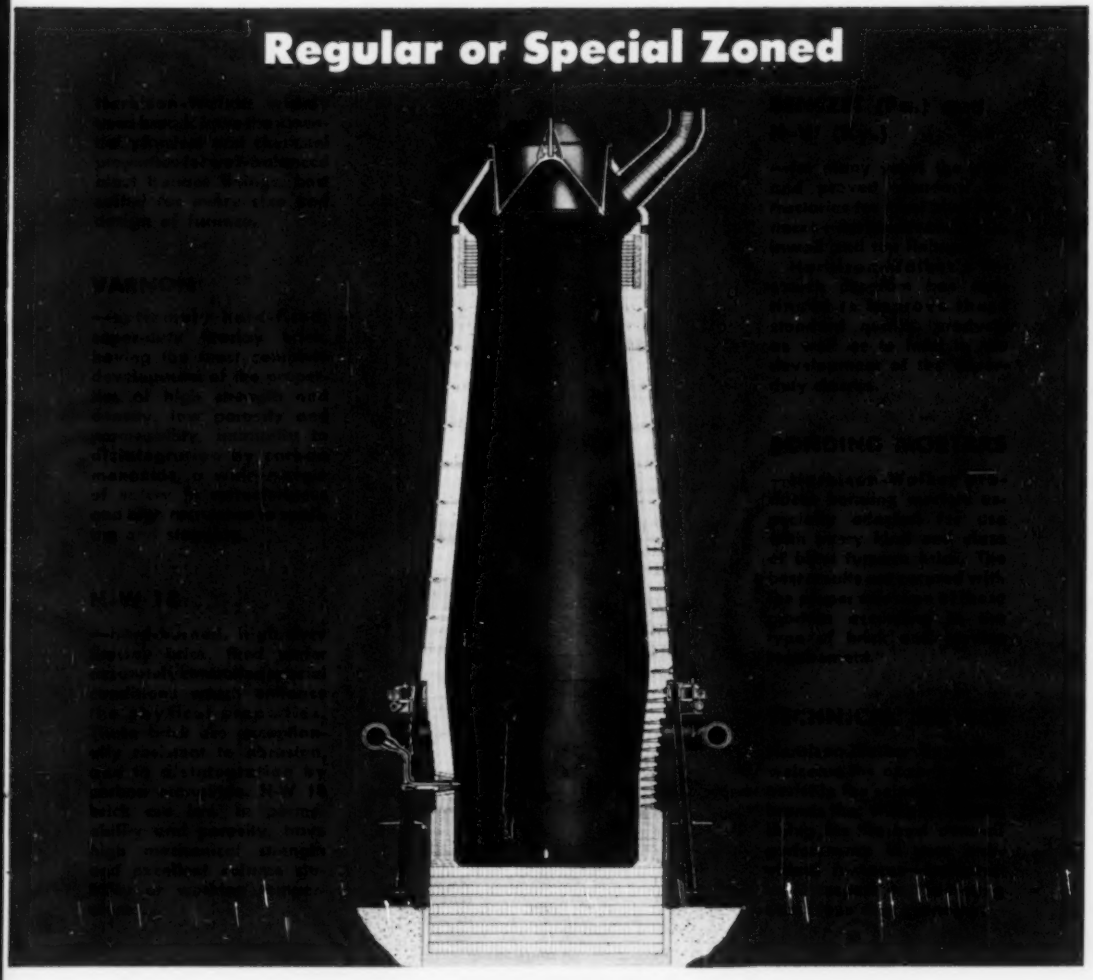

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ELECTROMET Data Sheet

A Digest of the Production, Properties, and Uses of Steels and Other Metals

Published by Electro Metallurgical Company, a Division of Union Carbide and Carbon Corporation, 30 East 42nd Street, New York 17, N. Y. • In Canada: Electro Metallurgical Company of Canada, Limited, Welland, Ontario

How VANADIUM improves engineering steels and helps conserve critical alloys

In these critical times when many alloying materials are scarce, you may be able to use vanadium to good advantage. Steels alloyed with vanadium meet most of the mechanical specifications for low-alloy engineering and structural steels. In fact, vanadium can often be used in engineering steels to replace at least part, if not all, of certain alloys now in critical supply.

The metallurgy of vanadium is well known. Small additions of vanadium—0.10 to 0.30 per cent—can be used effectively to give steel extra strength, toughness, and resistance to fatigue and wear. It improves engineering steels by increasing their yield strength without sacrificing ductility. The uniformly fine grain size of vanadium-bearing steels makes them tough and resistant to abrasion, fatigue, and impact.

Better Mechanical Properties

In the following table are typical analyses for carbon-vanadium and chromium-vanadium steels that are suitable for most applications where low-alloy, high-strength steels are required. The carbon-vanadium steel is compared with plain-carbon steel; and the chromium-vanadium steel, with chromium-molybdenum steel. Note the excellent properties of the vanadium-bearing steels.

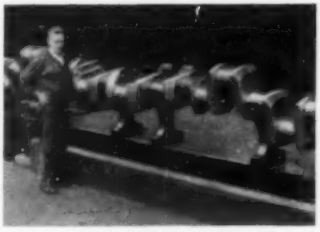

Fig. 1 — Vanadium increases the strength, toughness, and wear resistance of engineering steels for many machine parts, such as this large crankshaft.

Improves Cast Iron

A small addition of vanadium, usually from 0.10 to 0.25 per cent, refines the grain of cast iron, and materially increases its strength and hardness. Moreover, vanadium may be used in cast iron to replace at least part, if not all, of certain alloys that are now in short supply.

Vanadium in Rimmed Steel

An addition of approximately 1 lb. of vanadium per ton of steel produces non-aging characteristics in a rimmed steel. These non-aging properties, together with improved deep-drawing characteristics and the good surface inherent in rimmed steels, make these steels of particular interest at the present time.

Grades of Ferrovanadium

ELECTROMET produces ferrovanadium containing 50 to 55 per cent vanadium for the production of vanadium-bearing steels and irons. The alloy is produced in three grades with maximum 0.20, 0.50, or 3.00 per cent carbon and maximum 1.50, 2.00, and 8.00 per cent silicon, respectively. Each grade is specially adapted to fill the different requirements of iron- and steel-making.

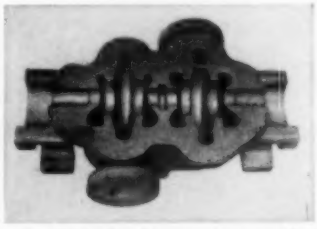

Fig. 2—Steel and iron castings treated with small additions of vanadium have high ductility and greater toughness and impact resistance.

Write for a copy of the booklet, "ELECTROMET Ferro-Alloys and Metals," which gives helpful information about the use of ferrovanadium and other alloying metals that ELECTROMET supplies. The booklet may be obtained from any ELECTROMET office: in Birmingham, Chicago, Cleveland, Detroit, Los Angeles, New York, Pittsburgh, or San Francisco. In Canada: Welland, Ontario.

Properties of Vanadium Steels Compared With Other Engineering Steels

Typical Analysis, %	Carbon Steel	Carbon-Vanadium Steel	Chromium-Molybdenum Steel	Chromium-Vanadium Steel
Vanadium	—	0.16	—	0.16
Carbon	0.50	0.49	0.50	0.50
Manganese	0.71	0.77	0.80	0.79
Silicon	0.19	0.15	0.30	0.31
Chromium	—	—	0.95	0.98
Molybdenum	—	—	0.20	—
Annealed and Furnace-Cooled				
Tensile Strength, psi	90,600	100,000	100,000	99,500
Yield Point, psi	48,900	66,000	50,000	64,100
Elongation in 2 in., %	23.3	25.0	23.0	28.4
Reduction of Area, %	37.8	49.1	45.0	59.0
Izod Impact, ft.-lb.	13.5	26.0	17.0	44.0
Quenched and Tempered				
Tensile Strength, psi	134,900	134,500	232,000	232,800
Yield Point, psi	110,800	128,000	214,500	224,200
Elongation in 2 in., %	18.3	18.3	10.0	10.4
Reduction of Area, %	54.1	56.6	39.0	43.1
Izod Impact, ft.-lb.	54.0	65.0	12.0	12.0

The term "Electromet" is a registered trademark of Union Carbide and Carbon Corporation.

Meet The Authors

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J. C. BRAY

I. S. SERVI

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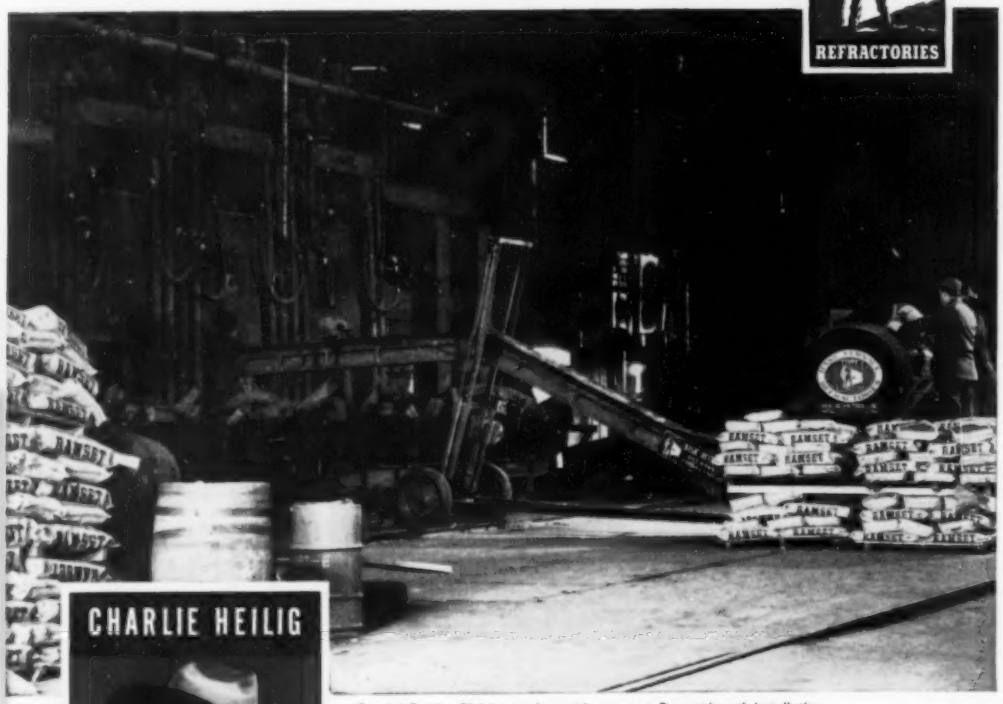

Special Service Division equipment in use on a Ramset hearth installation.

Charlie Heilig, manager of the Basic Service Division, joined the staff in 1944, with 23 years' experience in steelmaking, including years as an open hearth superintendent.

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Drift of Things . . . . . as followed by **Edward H. Robie**

EVERY year new words, phrases, or methods of expression rise to temporary fame. Such, for example, was the word *normalcy*, popularized by President Coolidge. A year or so ago we mentioned the new vogue for *presently* instead of *currently*, *presently* having usually meant *pretty soon* instead of right now.

A few years ago *Time*, we believe it was, began writing it $8 million instead of $8,000,000, and the practice of expressing large sums in this way has spread to most newspapers and magazines. We presume the reason for this style was to avoid a row of cyphers; there is no saving in the space used, at least not until we get into the billions. We still are not sure just how this should be read. Are we supposed to read it eight million dollars, or eight dollars million? If the former, then what do you do when the $8 comes at the end of a line, or column, or page? You see the $8 but your eye has to travel elsewhere to see the million. A well-known columnist puts it this way: 8 million $, which makes more sense, if one can get used to seeing a dollar sign all by its lonesome.

Perhaps the most noticeable comet in the present linguistic sky is the common use of the awkward expression "as of." This originally was legal jargon, and confined to financial reports and such where it sometimes had a useful significance. But now we read in the paper, "Unfilled orders *as of* Dec. 31 were $91,260,000." Why not *on*? In a newsletter: "The cost-of-living index made a new all-time high *as of* Feb. 15." Why not "The Feb. 15 cost-of-living index. . . .? And the radio: "*As of* right now, the forces of nature seem to be under control." Why the *as of*? Also, "The Jersey Central is shutting down services *as of* 1 o'clock tomorrow." Why not say *at*? In "All About Eve," "*As of* this moment, you are six years old." Again, why not *at*? And in the U. S. Steel report, "U. S .Steel's ingot capacity has been increased to give a total annual capacity, *as of* Jan. 1, 1951, of 33.9 million tons." Why not say *on*?

We suspect that those who use this bit of frippery unconsciously think they are utilizing one of the super niceties of expression. As a matter of fact, 99 times out of a hundred, they are using a clumsy phrase that could better either be omitted entirely or be replaced by one two-letter word.

Another adaptation of the last few years is use of the word *defense* instead of *military* or *war preparation*. Good psychology is back of this euphemism. No one can object to defense of the country, but everybody is fed up with war as a means of settling international difficulties.

AIME Student Problem

A variety of problems pertaining to the payment of AIME dues is constantly arising. Perhaps a few case histories will prove informative, so in this issue we will start with one that happens to have crossed our desk just recently.

A young man was elected a Student Associate in the fall of 1946 and paid his initial dues carrying him through 1947. He made no payment for 1948, 1949, or 1950, so was dropped at the end of 1949. He now wishes to be reinstated and to be assured that his membership will date continuously from 1947.

When AIME headquarters learned that he wished to be reinstated he was sent a bill for $1 for arrears in dues and $4.50 for current dues, including a journal subscription. The gentleman in question said it was not clear to him if payment of the $1 covered (1) payment in full for the back dues for 1948, '49, and '50; (2) reinstatement in good standing; or (3) whether or not his original election date would be retained.

In reply we told him: "It has been our practice to accept $1 as a reinstatement fee for Student Associates who have been dropped as owing two years' arrears in dues. This is equivalent to one half of the $2 formerly charged Student Associates as annual dues. Beginning in 1951, however, Student Associates who have not paid their dues by March 31 of any year are thereupon immediately dropped; thus no arrears will accumulate and the young man can later be reinstated without any charge other than dues for the year of reinstatement.

"To maintain his original election date a Student Associate or any other member must pay his dues continuously for the full amount, otherwise the date of his reinstatement becomes his election date on our records. To be recorded as a member of 1947, it would be necessary in the present case to pay $6, covering dues for 1948, '49, and '50, together with the $4.50 for 1951 which includes a journal subscription."

Bureau of Mines Films

An important activity of the Bureau of Mines that perhaps has not had the recognition it deserves is its motion picture work. Not only does the Bureau promote the making of films covering the mining, metallurgical, petroleum, and allied industries, but it maintains a free loan library of more than 16,000 reels. Last year its motion pictures were shown more than 177,000 times before audiences of 12 million people, not including showings by television.

This is one Government activity, and one of the more worthwhile ones it may be added, which costs the taxpayers comparatively nothing. The companies whose operations are depicted in the films have been eager to cooperate and to pay all production costs, even though the Bureau does not allow any trade marks, trade names, or advertising material to be shown. The only company identification is the name of the sponsoring company at the beginning and end of each film. Apparently the companies feel that even this modest mention of their name is worth the cost of the film in making for better employee morale and good public relations. Then, too, they have a sense of professional responsibility and pride in showing an interested public the highlights of their practice. They choose their own producing company, but the Bureau scrutinizes the scenario to make sure that the picture will be suitable for public showing on a noncommercial basis. Many, if not most, of the more recent films are in color. Both silent and sound films are included in the library.

Any companies that feel their operations are likely to be of sufficient public interest to warrant film recording should apply to M. F. Leopold, Bureau of Mines, Washington 25, D. C. Mr. Leopold, who joined the Bureau when it was created in 1910 and recently received the Interior Dept.'s gold medal for distinguished service, is well-known throughout the mineral industry. Those groups who wish to borrow the films for showing should apply to the Bureau of Mines Graphic Services Section, 4800 Forbes St., Pittsburgh 13. A catalog is available, as well as special publicity releases on all the new films as issued.

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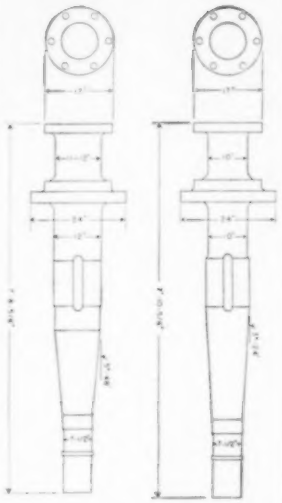
AVAILABILITY: Send us details of your prospective uses, so that we may suggest a source of supply from some 100 authorized foundries now producing ductile iron under patent licenses. Request a list of available publications on Ductile Iron . . . mail the coupon now.



DUCTILE IRON FORGED STEEL

COOPER-BESSEMER CORP., Mt. Vernon, Ohio, adopted ductile iron generator shafts to replace those of forged steel. Corresponding changes in design and dimensions are shown above.

Ductile iron provides unusual advantages. Its tensile strength runs between 83,000 and 94,000 p.s.i. as cast, on test bars cut from a full diameter extension on the small end. Unlike forged steel, which is a product obtained from outside sources, ductile iron shafts are cast as well as machined in the company's own plant. They make possible a low finished cost . . . 28% less than that of a forged steel shaft made to the dimensions shown above.

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A pocket size atomic radiation detector powered by flashlight batteries is expected to replace a 24 lb Geiger instrument. The new detector gives scale readings from 0.005 to 500 roentgens per hr, the safe to hot range.

Research and development for the military has passed the $1 billion mark and is increasing. Industrial research facilities, colleges and scientists will play a larger role under the long-range program of the Dept. of Defense Research Development Board.

A feedback electronic control circuit has been used to measure regulator carbon-pile resistance. Carbon-pile power dissipation was found to be more important than ambient temperature, and magnetic hysteresis permitted good regulation of large disturbances while tending to stabilize the regulated system in the steady state.

A third anhydrite kiln will be installed by Imperial Chemical Industries, Great Britain, which will raise the output of sulphuric acid from 100,000 to 175,000 tons per year. The company is cooperating with United Sulphuric Acid Corp., formed to produce acid from anhydrite.

Sulphuric acid requirements for the production of super-phosphates for the fertilizer industry may be reduced by using a mixture of nitric and sulphuric acids, and may eventually be eliminated by using nitric acid alone.

Gold production in 1950 is estimated at 26 million oz, 500,000 oz more than in 1949. Increased output of the U. S. and Canada accounted for this raise and balanced some reductions of other countries.

The British penny has gone the way of the American nickel. No longer available to Britons are the penny postcard, the penny bun, the penny bar of chocolate, and now the penny newspaper is three-halfpence.

A guided missile production plant at Pomona, Calif., is under consideration by the Navy Bureau of Ordnance in consideration with Consolidated Vultee Aircraft Corp.

The functions of the Munitions Board relating to manpower, industrial relations, and labor supply have been transferred to the Office of the Asst. Secretary of Defense, Anna Rosenberg. The Manpower Supply Div. has been organized to handle this work.

A new device breaks coal from a mine face by the force of compressed gas generated by chemical reaction within a reusable steel tube. The flameless reaction is started by a controlled electric current, and the unit cannot be detonated accidently by stray currents or dynamite.

Small photographs and printed material can be transmitted anywhere in the world with facsimile equipment under development by the Army Signal Corps. In addition, the transmitted material can be reproduced automatically on stencils, enabling pictures and news of front-line operations to be available for distribution within minutes.

A free piston gasifier, an opposed piston-type diesel, has a balanced reciprocating mass, resulting in little vibration. The elimination of crankshaft and connecting rods permits higher cylinder pressures than that of regular diesels.

To help you get the most out of the steels you're getting

The rearmament program is packed with headaches for steel users. And that is true whether you are working on defense orders or on non-military requirements.

If **you are working on defense materials you will of course get first call on critical steels. The steels you need for government defense orders will somehow be made available, but — you will still be faced with the necessity of quickly making the most out of those steels. For military needs are pressing and promise to become more so.**

If **you are working on purely civilian goods, your problem is an even more difficult one. You will find it almost impossible to obtain certain steel items that are essential for defense. To fill the gap you will have to employ substitute steels. You'll need help not only in selecting the proper substitute steels, but in using them properly.**

We are prepared to assist you in either situation.

The steel engineers and metallurgists we have assigned to this important job of helping you use steel more *effectively* are the same men who were largely responsible for the development of National Emergency steels — one of the outstanding metallurgical accomplishments of World War II. These men can call upon the facilities of the most completely equipped steel research laboratories and the largest steel making plants in America. They can bring to the solution of your problems the very latest ideas and time-saving techniques in the working and treatment of steel. We urge you to draw freely upon this rich reservoir of experience.

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CHEMICALS AND METALS

Properties Influencing

Wear of Metals

by T. L. Oberle

Wear of metals costs billions of dollars annually; an amount exceeded not even by the loss through corrosion of metals. The importance of metal wear is emphasized in this special JOURNAL OF METALS feature. It deals not only with factors influencing wear of metals, but also is a study of methods to reduce or eliminate this costly waste.

DURING the past 50 years, engineering materials have been strengthened so successfully that materials run for thousands of hours. Failure is now often the result of various types of surface deterioration that cannot be studied readily by tension, impact, or hardness tests. The simple trial and error approach to problems involving complex phenomena of wear is time consuming and costly and results in little information of permanent value. Meanwhile wear loss costs billions of dollars annually; a cost that may not be exceeded even by the tremendous annual cost of corrosion of metals.

In 1676, Hooke demonstrated that stress was proportional to strain at loads below the elastic limit. In 1881 Herz[1] published his pioneer work on the elastic deformation of solid surfaces. The elastic relationships of materials under load have been developed in recent years by Timoshenko and others.[2,3,4] Despite the importance of the influence of the elastic properties upon the deflection and the stresses in metal surfaces under load, there appears to have been no conscious effort on the part of metallurgists to alter the elastic modulus of metals to control wear. Efforts are being directed, however, toward raising the yield strength of metals to reduce wear.

The elastic modulus of a material is the ratio of stress to strain. These relationships are shown graphically in Fig. 1. High modulus metals, A in Fig. 1, have a steep slope indicating that even a high stress causes relatively little elastic strain. Low modulus metals, B in Fig. 1, have a shallow slope, showing that a small stress results in a relatively large elastic strain.

The limit of elasticity of metals, Fig. 1, is that point where the stress-strain curve deviates from a straight line. This point may be identified as either the elastic limit of stress or the elastic limit of strain. The elastic limit of stress usually is reported for engineering materials as the yield strength of the material. The values of yield strength on engineering materials are usually slightly higher than the true elastic limit of stress. The elastic limit of strain is seldom reported as such, but an indication of its magnitude can be determined by dividing the elastic limit of stress of a material by its elastic modulus.

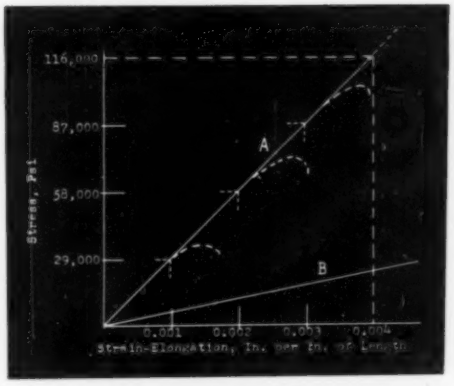

Fig. 1—Schematic stress-strain diagram for steel.

High hardness, sought after to increase wear resistance, actually increases the amount of elastic deformation that can be tolerated by a steel. A much greater increase in the elastic limit of strain is possible by means other than increased hardness if the factors that influence the modulus of elasticity of metals are understood and applied.

Since accurate determinations of the elastic limit of strain are not available for many materials, a convenient factor may be obtained by dividing the Brinell hardness of a metal by its elastic modulus. The substitution of Brinell hardness for elastic limit of stress may be justified by the close relationship that exists between them, as illustrated by mechanical properties charts of hardened and tempered steels. This is further substantiated by the work of Tabor[5] who states: "Hardness measurements are essentially a measure of the elastic limit of the material being examined."

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The ratio of Brinell hardness to elastic modulus, multiplied by 10^6, will be called Modell in this paper. Materials are listed in Table I in order of decreasing Modell. Modell gives an indication of the depth of penetration that a metal can tolerate without exceeding its elastic limit. Thus, chromium plate will recover elastically from more than 100 times the amount of deformation that would cause tin to plastically yield. Gray iron and steel appear twice in Table I, since their Modell undergoes a three-fold increase on hardening. Materials of high Modell behave like a spring, absorbing energy and preventing loads from building up to a high value. Rubber impellers in sludge pumps and rubber tires on automobiles illustrate the use of elastic materials to prevent load buildup.

The low Modell materials of Table I have little capacity for absorbing energy elastically. These metals have been used as bearing metals. The ready conformability or plastic flow of bearing materials permits some reshaping of the part in service to adjust for inevitable misalignments. Although no quantitative relationship has been established, the greater the extent of the elastic range of a metal, the smaller will be the plastic range and vice versa.

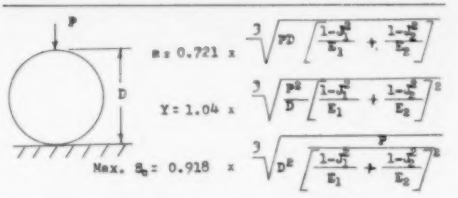
Data indicate that the surface deterioration of high melting point materials is related to their Modell value. More precise data may show that surface stability is closely related to the area under the curve when Brinell is plotted against Modell. This area is closely related to the capacity of a metal surface to absorb or store elastic energy. The triangular area is $\frac{(\text{Modell} \times \text{Brinell})}{2}$ or $\frac{(\text{Brinell})^2}{2E}$, while the amount of energy that can be stored in a unit volume of spring material equals $S^2/2E$ where S is the maximum allowable stress. Thus, the modulus of resilience or elastic energy stored per unit volume of material at the elastic limit may be an accurate indication of the stability of a metal surface in frictional applications. While the accuracy of data now available does not permit a choice between Modell and modulus of resilience, the simpler Modell factor will be used in this discussion.

Table I. Modell Factors for Various Engineering Materials

Material	Condition	E x 10^6	Bhn	Modell Factor
Alundum (Al_2O_3)	Bonded	14	2000	143
Chromium plate	Bright	12	1000	83
Gray iron	Hard	15	500	33
Tungsten carbide	9 Pct Co	81	1800	22
Steel	Hard	29	600	21
Titanium	Hard	17.5	300	17
Aluminum alloy	Hard	10.5	120	11
Gray iron	As cast	15	130	10
Structural steel	Soft	30	150	5
Malleable iron	Soft	25	125	5
Wrought iron	Soft	29	100	3.5
Chromium metal	As cast	30	125	3.5
Copper	Soft	16	40	2.5
Silver	Pure	11	25	2.3
Aluminum	Pure	10	20	2.0
Lead	Pure	2	4	2.0
Tin	Pure	6	4	0.7

Equations for the elastic behavior of metals have been presented by Roark.[6] For a sphere in contact with a flat surface the relationships are given in Table II. The radius of contact and total deformation increase as the elastic modulus is lowered. The maximum unit stress in compression between the two bodies is lowered by a decrease in the elastic modulus of the sphere, the flat, or both. These elastic relationships indicate that the elastic modulus of a metal is of prime importance in determining actual loads on metal surfaces. On the other hand, it has been recognized that hardness has an influence upon the rate of surface deterioration of metals. As the Brinell hardness of a metal increases, the resistance to plastic yielding under load also is increased. The combination of low elastic modulus, which spreads out the load, with high Brinell hardness, to resist the applied load, should result in maximum possible resistance to surface deterioration. This suggests that surface stability may be related directly to Brinell hardness and related inversely to elastic modulus. This relationship, Brinell: E.M., or Modell, was shown to be a measure of the elastic limit of strain of a metal. Some materials used for cylinder liners are listed in Table III, with their Modell value and a qualitative indication of wear.

Table II. Relationships of a Sphere in Contact with a Flat Surface



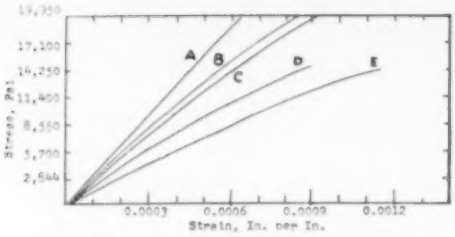
P - Applied Load, Lb
a - Radius of Contact
D - Diam of Ball, In.
Y - Total Deformation
J_1 - Poisson's Ratio for Test Specimen
J_2 - Poisson's Ratio for Ball
S_c - Unit Compressive Stress
E_1 - Elastic Modulus of Test Specimen
E_2 - Elastic Modulus of Ball

Additional evidence shows that surface deterioration of metallic materials is closely related to the elastic limit of strain of the material. The work of Bowden and his associates[7 to 13] and others[14] has shown that loads transmitted between two metals are: 1—Carried by an extremely small fraction of the surface area available; 2—that instantaneous temperatures between metals in contact may approach the melting points of the metals at points of contact; and 3—that sliding movement between metals takes place in an intermittent *slip-stick* manner that can be divided into three types depending upon the melting points and similarity or dissimilarity of the two materials.

Soft, low-melting point bearing alloys are most susceptible to surface welding, but because of the ease with which they break a welded bond by localized softening they suffer little damage due to welding on steel. Metals of higher melting temperature undergo more rapid slip-stick of smaller magnitude. High melting point metals also are susceptible to seizing or welding together with the resultant destruction of the surface area or the entire part. This type of failure occurs when the temperature

Table III. Materials Used for Cylinder Liners

Material	Bhn	E x 10^6	Modell Factor	Liner Wear
Alundum (Al_2O_3)	2000	14	143	Least
Bright Cr plate	1000	12	83	Second
Hard gray iron	500	15	33	Third
Hard steel	600	29	20	Fourth
Soft gray iron	150	15	10	Fifth
Soft steel	180	29	6	Most



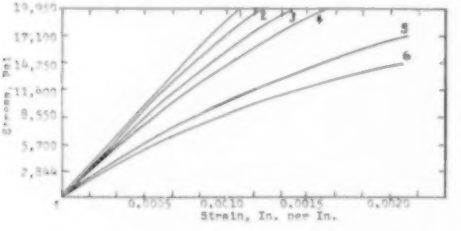
Steel No.	Perforations in Steel 0.080 In. Thick	Elastic Modulus 1420 Psi Load	Elastic Modulus 12800 Psi Load
A	None	30,000,000	30,000,000
B	0.025 In. Diam Holes	25,800,000	23,800,000
C	Slots, 0.012x0.040 In.	24,400,000	21,200,000
D	Slots, 0.012x0.060 In.	18,350,000	14,500,000
E	Slots, 0.012x0.120 In.	14,200,000	11,330,000

Fig. 2—Stress-strain curves of perforated steels.[20]

and pressure of the surface of two high melting metals are sufficiently high to cause welding over extensive areas. The fact that some high melting point materials, such as ferritic iron, are highly prone to seize, and lower melting point material, such as gray iron, has excellent running qualities indicates that some mechanical properties of metals related to the melting point as well as to other factors may be extremely influential in metallic wear. From the work of Bowden and his associates, there can be little doubt that hardness has been overemphasized as a wear preventive property.

Bowden's work shows the importance of molecular cohesion and welding of metals in sliding contact as a possible means by which metal is lost from surfaces during wear. Elam[21] disclosed that when a metal is stressed within the region of perfect elasticity, there is no rise in temperature. The high temperatures observed by Bowden on metal surfaces in sliding contact indicate that the metals were at discreet localities loaded beyond their yield point. The number of such localities stressed above the elastic limit will be decreased as the elastic limit of strain or the Modell is increased. There is evidence that the friction of metals in sliding contact is lowest for metals of high Modell.[16]

Additional factors enter into the differences between the three types of sliding observed by Bowden. The relative melting points of the two metals in contact influence tendencies toward seizure, such



Iron No.	Graphite Pct	Graphite Area	Graphite Size	Elastic Modulus 1420 Psi Load	Elastic Modulus 12800 Psi Load
1	1.85	4.4	6-7	19,650,000	19,200,000
2	1.53	5.0	5	17,800,000	17,500,000
3	2.50	10.8	4-5	16,500,000	15,100,000
4	2.44	10.9	4	16,300,000	12,750,000
5	2.92	14.0	3-4	12,750,000	9,480,000
6	2.60	14.8	3	11,330,000	7,670,000

Fig. 3—Stress-strain curves of gray irons.[20]

as the catastrophic failure when chromium plate is run against chromium plate. The failure of a metal to run well on similar metals probably is influenced by Hume-Rothery's[17] atomic size factor, which could be responsible for the seizure or rapid wear of steels containing large amounts of ferrite. The thermal conductivity of a metal may influence the surface temperatures obtained during sliding under load. Only when such factors are favorable for the prevention of wear and seizure can two materials of low modulus and high Modell run well together under heavy loads.

Factors that cause the yield strength or hardness of a metal to vary have been investigated for industrial purposes and are described so fully in literature that no discussion is necessary. Because of the difficulties in measuring the elastic modulus and an apparent lack of a strong need for accurate elastic modulus data, the factors that influence the elastic modulus of metal surfaces are not clearly defined. The inherent and controllable factors influencing the elastic modulus of metals have been discussed by Mack[18] and Dorn and Tietz.[19] The elastic modulus of metals is influenced by *melting temperature* and *atomic volume*. The elastic modulus of low melting metals tends to be low, and the elastic modulus of high melting metals tends to be high. There is a tendency for elastic modulus to decrease as the atomic volume increases.

In addition to the inherent factors determining the general level of elastic modulus, some metals are highly susceptible to variations in elastic modulus that may be controlled within limits during the fabricating, casting, or heat treating stages of manufacture. Some controllable factors that may alter the elastic modulus of metals are heat treatment, interruptions, and anisotropy.

The influence of heat treatment upon elastic modulus is limited to a few nonferrous alloys. The aging of some age-hardenable alloys results in a small increase in elastic modulus. Most metals and alloys such as steels virtually have no change made in their elastic modulus by heat treatment of any kind.

Interruptions to metal continuity may take the form of cracks, gas cavities, or voids of any kind. The graphite present in gray iron is included in this classification because its low modulus (700,000 psi) apparently permits it to behave somewhat as though the enclosure around it is empty. The elastic modulus of metals decreases in direct proportion to the volume of spherical type voids.[19] Elongated interruptions, such as flakes or cracks, decrease the elastic modulus of a metal in a direction transverse to the long dimension of the discontinuity. This was observed by Thum and Ude[20] on steel sheets in which were sawed various shapes of perforations, and confirmed by Schwartz and Junge[19] in their investigation of nodular and flake graphite in irons. Fig. 2, replotted from Thum and Ude's data, shows the effect of increasing slot length in lowering the elastic modulus of steel sheet. The slotted steels tested by Thum and Ude show a distinct bend in the modulus curve similar to that of gray iron in Fig. 3. With a random orientation of graphite flakes in gray iron, the reduction in elastic modulus in all directions is quite pronounced.

Single crystals have a vectorial character, exhibiting properties that are different in one crystallographic direction than in another, and are said to be anisotropic. The study of the elastic modulus of me-

tallic single crystals has provided information such as summarized by Sayre[21] in Table IV. The elastic modulus of a single crystal of iron is 19,200,000 psi in a direction parallel to any one of the three major axes. As the direction of load is tilted away from these major axes, the modulus increases until a maximum value of 41,240,000 psi is obtained when the load acts along the space diagonal between the three axes. Polycrystalline metals, under certain conditions, will give up their random crystalline arrangement and assume a preferred orientation. A preferred orientation of crystals in a polycrystalline metal exists when the individual grains have their principal planes in parallel alignment. Metals with a preferred orientation exhibit many peculiarities associated with single crystals.

Ruder[22] and Morill[23] have described techniques used to produce highly preferred (95 pct) grain orientations in iron-silicon transformer core sheets. Alternate rolling and heat treating produce a directional alteration of magnetic properties sufficient to reduce transformer core losses to 20 pct of the losses with random oriented iron-silicon alloy cores. This is one of the rare instances where crystallographic orientation is controlled for industrial purposes.

Highly preferred orientations are sometimes developed during electrolytic plating. The brightest

Table IV. Young's Modulus and Shear Modulus of Cubic Metals

Material	Structure	Elastic Modulus E x 10^6 (111)	Elastic Modulus E x 10^6 (100)	Shear Modulus G x 10^6 (111)	Shear Modulus G x 10^6 (100)	Elastic Anisotropy E_{111}/E_{100}	Elastic Anisotropy G_{100}/G_{111}
Aluminum	FCC	10.81	9.24	3.55	4.12	1.18	1.13
Gold	FCC	16.21	5.97	2.56	5.83	2.7	2.2
Copper	FCC	27.59	9.67	4.41	10.95	2.86	2.47
Copper, 25 Pct Au	FCC	24.60	8.82	3.98	9.39	2.79	2.37
Copper, 28 Pct Zn	FCC	26.17	7.54	3.55	10.38	3.5	3.0
Iron	BCC	41.24	19.20	8.68	16.78	2.15	1.94
Tungsten	BCC	56.89	56.89	22.04	22.04	1.00	1.00

chromium plate deposits are produced under conditions that cause almost all of the crystals to be aligned with their closely packed (111) planes parallel to the surface of the plate. This should result in a low elastic modulus when measured normal to the plated surface. The degree of elastic anisotropy of chromium single crystals could not be found in the literature. Bureau of Standards[24] modulus determinations upon chromium plate in the highly preferred and in the random orientation suggests that chromium crystal anisotropy may be quite pronounced. The special conditions that cause a highly preferred orientation have never been exploited to their fullest extent in developing materials for wear applications.

Rosenberg[2] expressed the opinion that some types of wear may be related to the elastic modulus of materials. German and Russian articles[25,26] have indicated the use of methods intended to extend the range of low modulus gray irons to high load applications through the use of reinforced castings. The selection of materials for highly loaded applications appears to follow a trend toward high Modell materials. There has been, however, little or no conscious recognition of the vital part played by the elastic properties of metals on the survival of metal surfaces.

Piston rings and cylinder liners are applications where low wear is desired in both members. The

Table V. Comparison of Elastic Properties of Malleable and Gray Iron

Material	Microstructure	Graphite Vol., Pct	E x 10^6	Bhn	Modell Factor
Steel	Pearlite	0	29	200	6.9
Malleable iron	Pearlite	10	26	200	7.7
Gray iron	Pearlite	10	12	200	16.7

use of low melting bearing alloys is precluded by the high temperatures, high pressures, poor lubrication, and the elasticity requirements of the rings. Gray iron running against gray iron or hardened steel has been used. In recent years, either the ring or liner surface have been chromium plated to reduce wear of both members.

The matrix of gray iron may be identical with that of a steel, but large graphite flakes in gray iron may reduce the elastic modulus to 1/3 that of steel. The elastic modulus of gray iron is not constant, but varies with the applied load. Rosenberg[2] reported that a gray iron with 16,000,000 elastic modulus at 4500 psi load has only 7,500,000 elastic modulus at 22,500 psi load.

The success of gray iron in resisting engine wear is attributed by some engineers to the lubricating qualities of graphite. Yet, malleable iron containing the same amount of graphite as gray iron cannot be substituted successfully for gray iron in many engine parts. Table V illustrates some real differences in elastic properties between malleable iron and gray iron that exist as a result of the shape or form of the graphite particle independently of the graphite volume.

The difference in Modell values alone is sufficient to account for superior running qualities of gray iron. Gray irons containing finely dispersed graphite, dendritic, eutectiform, etc., may have elastic modulus values as high as malleable iron, so that more knowledge than just that the iron was cast gray is necessary to judge the suitability of the material for frictional applications.

Poppinga,[27] Hegh,[28] MacKenzie,[29] Jominy,[30] Smith,[31] Lane,[32] and others indicated that shape or form of graphite flakes in gray iron is influential in resisting wear or improving running qualities. Coarse, thick graphite flakes of random orientation, meeting the AFA designation of type A graphite, are preferred. Such flakes cause a greater reduction in elastic modulus than other forms of graphite. Data obtained by Lane[32] on the wear loss in milligrams for gray irons of 89 R_B with different shaped graphite particles are shown in Table VI.

While Lane gave no elastic modulus data for these irons, flake graphite iron has a substantially lower elastic modulus than the dendritic graphite iron, and therefore a higher Modell. This difference in Modell for irons of the same hardness indicates that varia-

Table VI. Wear Loss for Gray Iron

Alloy No.	Rockwell B	Flake Graphite, Wt Loss, Mg	Dendritic (finely dispersed) Graphite, Wt Loss, Mg
A	89	14.7	26.8
B	89	16.4	26.1
E	89	16.6	25.3
H	89	14.0	29.5

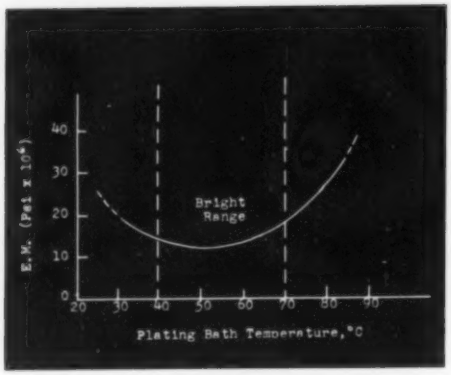


Fig. 4—Elastic modulus of plated chromium.

tions in elastic modulus influence wear. Shuck[20] reported elastic modulus, hardness, and wear on a number of gray irons cast in ¼ to 1½ in. square bars to produce graphite from coarse type A to fine eutectiform dispersion. Curves plotted from Shuck's data on seven unalloyed gray irons will show: 1—Wear increases as hardness increases. 2—Wear decreases as modulus decreases. 3—Wear decreases as Modell increases.

Item No. 1 is contrary to expectation. This reversal of the usual trend is the result of the sharply increasing modulus that occurs simultaneously with the hardness increase. For most materials, the elastic modulus is unchanged during hardening and its influence is not felt. Shuck's data on alloyed irons confirm these trends. It is unfortunate that most other papers on metal wear do not give sufficient data to permit an analysis of the influence of elasticity upon wear. The data from various sources indicate that for wear applications, gray iron should be cast with coarse graphite flakes and hardened by heat treatment to produce maximum Modell, rather than to obtain high hardness in an as-cast high strength iron with a resultant high elastic modulus. Nodular irons described by Morrough[24] and Gagnebin[25] have high elastic modulae like malleable irons because of the spherical graphite particles. Hence, they are limited to moderate Modell values.

Bureau of Standards[24] describes a technique for determining the elastic modulus of chromium plate and gives the first published data upon the elastic modulus of plated chromium. For current densities in the range of 0.5 to 4 amp per sq in. a minimum in elastic modulus (about 12,000,000) is obtained in the plating temperature range of 40° to 70°C as shown in Fig. 4. Information reported in 1943 by Hume-Rothery[26] shows that bright chromium deposits are obtained in the plating temperature range of 40° to 70°C with current densities of 0.5 to 4 amps per sq in. This is illustrated in Fig. 5 taken from Hume-Rothery's paper. The shaded area between zones II and III is the region of brightest deposits. When plating conditions were adjusted to obtain the brightest plate, Hume-Rothery found the greatest degree of perfection of the orientation of the (111) planes parallel to the surface of the plate. To either the right or the left of the shaded zone in Fig. 5 the perfection of alignment of the (111) planes decreases and a more random crystal structure is observed in zones I and IV. Wood[27] observed that the orientation of crystallographic planes of plated deposits is related directly to the brightness or reflectivity of the deposit. Snavely[28] concurs with Hume-Rothery in finding that (111) planes are preferredly oriented parallel to the basis metal in bright chromium deposits.

Arkharov,[29] Hosdowich[30] and others presented data to show that minimum wear of chromium plate occurs when plating conditions are such as to give the brightest deposits. Thus, through three different investigations low modulus, highly preferred orientations, and maximum wear resistance are all somewhat loosely tied together by means of their common denominator — *brightness of deposited plate*. There is a need for a single investigation covering the elastic modulus, brightness, and crystallographic orientation of plated chromium and relating these properties to the different rates of surface deterioration of matte, bright, and milky chromium deposits.

A second cause of low modulus in chromium plate may be the presence of cracks developing in highly stressed deposits during plating. Coyle[31] showed the presence of cracks in chromium plate and Cohen[32] and Snavely[33] established that a Cr_2O_3 film fills the cracks that form during plating. Bureau of Standards data[24] show that the elastic modulus of plated chromium is raised almost as high as wrought chromium (36,000,000) by heating to 1200°C. Unless a Cr_2O_3 filled crack can heal over and produce solid metal, it appears likely that the preferred orientation of plated chromium is primarily responsible for its low elastic modulus and superior wear qualities.

Outstanding wear results have been observed with the use of some materials normally considered abrasive. Milligan[34] reported wear data on sur-

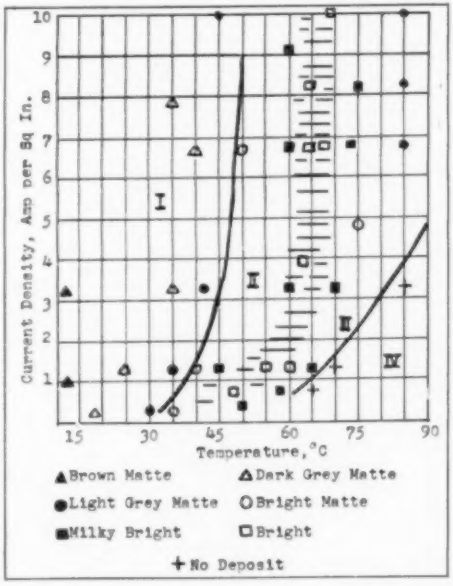


Fig. 5—Influence of current density and plating temperature upon type of deposited chromium.

face plates as shown in Table VII. These data show that all surface plates are worn less by a low modulus gray iron than by a hardened steel and that the low modulus gray iron itself wears less than hardened steel. Also, the data show that high Modell surface plates resist wearing much more than low Modell materials.

Tests conducted in the Caterpillar Research Laboratory have shown Alundum to possess excellent wear resistance. Many powder metallurgy products combining metals and ceramics have excellent future possibilities for wear and frictional applications. Powder metallurgy techniques may permit the combining of hard particles with a suitable binder to yield an aggregate of low elastic modulus.

Bowden has shown that metals with low melting points up to 787°F smear during sliding on steel without damaging the steel. High melting metals with melting points down to 1761°F exhibited type I sliding by grooving the steel. Aluminum marked the transition point between low and high melting metals by sometimes exhibiting type I and sometimes type II sliding on steel. Most successful bearings contain a low melting constituent or overlay, like lead or tin which, at bearing temperature and

Table VII. Wear Data on Surface Plates

Surface Plate Material	Surface Plate Wear, In. per 100 Days: Cast Iron Slider	Surface Plate Wear, In. per 100 Days: Hard Steel Slider
SiC (Carborundum)	0.00005	0.000075
Al_2O_3	0.00005	0.000075
Granite	0.0020	0.0050
Cast Iron	0.0070	0.0210
	Slider Wear, In. per 100 Days: Cast Iron Slider	**Slider Wear, In. per 100 Days: Hard Steel Slider**
SiC	0.0005	0.0015
Al_2O_3	0.0004	0.0015
Granite	0.0004	0.0050
Cast Iron	0.0050	0.0060

pressures, reach an incipient liquid state. Needless to say, the elastic modulus of liquids is quite low.

One requirement of a cutting tool is to produce sufficient load to exceed the elastic limit of the workpiece without endangering the tool. The elastic relationship in Fig. 6 indicates that this can be accomplished by a high-modulus, high-Brinell material. Curve A of Fig. 6 is probably typical of all good cutting tools like diamond, tungsten carbide, and tool steels loaded with alloy carbides. The high Modell value of tungsten carbide, item 22 as in Table I, has a somewhat different significance than a high Modell value of low modulus materials. Because usual loads on a tungsten carbide cutting tool are much smaller than the material can stand, only a small part of the possible elastic deformation is used. The unused portion of the elastic region of the stress-strain curve represents reserve capacity of the tool which insures long cutting life.

Gray iron at Bhn 300, steel at Bhn 600, and tungsten carbide at Bhn 1800 all have a Modell value of about 22. Since the stress upon gray iron at its elastic limit is less than the load that steel or tungsten carbide can carry, gray iron can be deformed (machined) by tool steel or tungsten carbide with little damage to the tool. This indicates a need for similar modulae for two metals running against each other when low wear is desired for both materials.

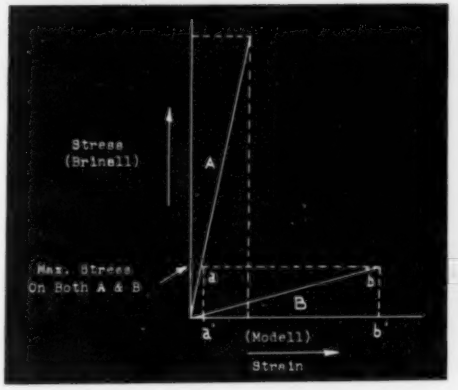


Fig. 6—Schematic stress-strain diagram for cutting tool and machineable materials.

As a general rule, the difficulties of machining increase with the hardness of the work. However, if the hardness value is to be kept low for easy machining, the Modell value or wear resistance may be increased by lowering the elastic modulus of the material. Low modulus improves resistance to wear and at the same time may even improve machineability. High Modell materials, if gray iron is any criterion, machine more readily than low Modell materials of the same hardness. A considerable economic advantage would result from developing wear resistant materials of low hardness. In gray iron, this would involve some degree of control of graphite flake size and orientation. When methods of producing extremely low modulus gray irons are developed, running qualities and wear resistance should be improved. Maximum wear resistance will result if some of the graphite flakes near the surface can be aligned parallel to the loaded surface.

Fretting corrosion or false Brinelling of metals in contact under load, while subject to vibrational forces, may be improved by the use of low modulus materials. Both Tomlinson[45,46] and Albert[47] suggest that fretting is related to the molecular properties of metal, as are elasticity, friction, etc., and not to hardness or structural properties. Tomlinson[45] proposed a molecular theory of friction in which the elastic modulus of metals is closely related to friction. High damping capacity that accompanies low elastic modulus may function to minimize fretting of metals. The use of materials such as Al_2O_3 also may assist in eliminating fretting from both the standpoint of elasticity and surface oxidation resistance.

Many diesel engine parts will run for more than 20,000 hr when the engine is supplied with clean fuel, oil and air. Increasing amounts of dust and dirt accelerate wear so rapidly as to completely wear out those same parts in less than 100 hr. The influence of the amount of grit upon the tendency to gall was shown by Dayton.[48]

Foreign particles may cause many areas of plastic flow when the loads transmitted between the surfaces would generally otherwise be within their elastic limit. The amount of elastic deformation that the surfaces of metals of different Modell can undergo is shown graphically in Fig. 7. For particles of foreign matter smaller in diameter than A in

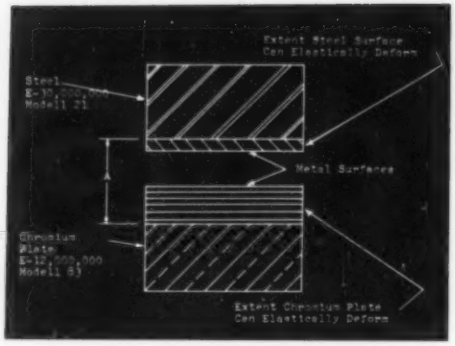


Fig. 7—Relative amounts of elastic deflection of surface metal possible for hardened steel and chromium plate.

Fig. 7, the large elastic yielding of high Modell chromium plate should result in a low wear rate for both surfaces. Particles coarser than A will cause the most wear on the material of lower yield strength. The elastic cushion provided by low Modell materials helps minimize wear only as long as the foreign particles do not exceed a critical size, which is dependent upon the elastic *give* of the metal surfaces, the load, and the minimum clearance between the surfaces.

Many laboratory tests have been developed to evaluate metals for resistance to wear. To produce measurable wear quickly, abrasives such as Al_2O_3 and SiC are used in laboratory wear test machines. These abrasive particles differ in hardness, elastic modulus, and possibly in particle size from the dust and dirt particles to which the metals will be exposed during service. For these, and possibly many other reasons, wear experts advise extreme caution in applying the results of accelerated laboratory tests to actual engineering problems.

The subject of surface finish has figured prominently in discussions of surface deterioration. Tomlinson[46] and Albert[47] have shown that smooth surfaces favor fretting of metals. Bowden's associates have shown that the actual area of contact is independent of surface roughness. From theoretical considerations, it would appear that moderate variations in surface finish are not important except possibly in the case of soft bearings running against a rough file-like shaft. In the past, considerable controversy existed on the subject of smooth vs. rough surfaces. Swigert,[48] Wallace[50] and others reported that smooth surfaces resist wear and fretting better than rough surfaces. M. O. Teetor[51] conducted tests to show that the load carrying capacity of surfaces was increased by various degrees of surface roughening up to 0.030 in. deep grooves. Interrupted surfaces now are mechanically or chemically applied to many highly loaded parts to facilitate break-in and improve running qualities. Such interruptions probably lower the elastic modulus of the metal surface. This protection usually is only temporary, since the surface wears smooth in time. Gray iron, however, with built-in interruptions permanently retains its as-new running qualities.

Brinell developed an indentation hardness test that measures elastic limit of the material tested. Meyer,[52] Mahin[53] and others have worked toward an indentation test that would measure *absolute hardness* or the hardness without cold working of the metal to influence the test results. Innes,[54] Esnault-Pelterie,[55] Auerbach[56] and others have attempted to develop a simplified method of measuring Hertzian[57] hardness. Hertz defined hardness as the pressure at the center of the surface of contact at the moment when permanent deformation begins to take place. Williams[58] quotes a report of the Institution of Mechanical Engineers on the measurement of Hertzian hardness as follows: "Unfortunately, the elastic limit of most engineering materials is not very definite, and the measurement of the small contact area is difficult, so that the method cannot be used as a general test despite its rational basis."

Rosenberg[4] used a spherical indenter on a plane surface to measure the elastic modulus of a metal with the aid of equations for elasticity developed by a Russian mathematician named Bussinesk. Bussinesk's equations of elasticity are identical with those of Timoshenko. It is possible that intensive development work based upon Timoshenko's equations and the use of a spherical diamond indenter will provide a satisfactory tool for measuring the elastic modulus of metal surfaces. The principal barrier to success has been the difficulty of sharply outlining the area of elastic contact between the sphere and the plane. The methods of outlining the elastic contact area used by Esnault-Pelterie and Rosenberg have yielded results in the Caterpillar Tractor Co. Research Laboratory, which approach the required accuracy. A practical measuring tool using a diamond sphere in contact with a flat polished surface of the test material is now under development. The measurement of elastic contact area approximately 0.015 in. diam within about 0.00003 in. is necessary to give the elastic modulus accurately to about 1,000,000 psi. An improved practical method of sharply outlining the elastic contact area to give consistently reproducible results on all materials would establish this device as a new and useful test machine.

The Martens and Huggensburger methods of measuring the elastic modulus of metals in tension are accurate, but slow and expensive when compared with an indentation type of test. There are other reasons for favoring an indentation type of test. Tomlinson[45, 46] and Rosenberg[4] uncovered experimental evidence of abnormal elasticity of metal surfaces. Tomlinson observed that metals appear to exhibit about eight times their normal elasticity in the extreme surface layers. Rosenberg found evidence to suggest that metal surfaces may deflect more than expected at very low load levels. A tension-type test that averages surface and center modulae will not be satisfactory to explore the possibilities of abnormal elasticity of metal surfaces. The points of dissimilarity in test results between scratch (Mohs) hardness and indentation hardness also suggest that the secret of resistance to wear is tied up in the as yet unexplored and inaccessible elastic properties of metal surfaces.

Evidence shows that wear of an engineering material is closely related to the elastic limit of strain of the material. A practical measure of the elastic limit of strain of materials is the Brinell hardness multiplied by 10^6 divided by the Elastic Modulus. This relationship has been called Modell. The Modell of materials is thought to be significant in many engineering applications where surface deterioration is encountered.

Higher Modell values can be obtained by increas-

ing the hardness or by decreasing the elastic modulus of a material or both. Since methods of increasing hardness have been well explored, greatest gains appear in the direction of lowering the elastic modulus of materials. The introduction of interruptions to the continuity of a material and the control of crystal orientations to produce low surface modulus in the proper direction are the two most likely means of altering elastic modulus to create high Modell materials for the future. Research directed toward controlling the elastic modulus of metals should be increased greatly.

The haphazard development of improved wear resistant materials would be accelerated by the development of a simple indentation type of test for measuring the elastic modulus of surfaces. Results from such a test instrument, coupled with indentation hardness test results, will establish the Modell value which should replace hardness as an index of the surface stability of wear resisting materials.

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EXTRUDING Copper and Brass

by W. W. COTTER, Sr.

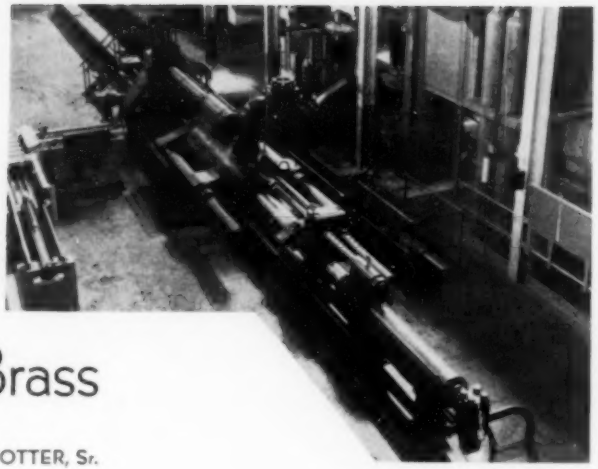

Fig. 1—Loewy 2400-ton hydraulic extrusion press.

ALEXANDER DICK of London, England, is given credit for being first in the extrusion of brass, but it took many years of experience with this revolutionary thought before engineering could provide equipment capable of transforming any and all plastic metals. Dick, of the Delta Metal Co. in London, aside from brass making, was a producer of lead pipe and coated products in 1895. When a mixture of 60 pct copper and 40 pct zinc was attempted by Dick at its proper plasticity, it required a ram pressure of about 50,000 psi, with a cherry red heat to move it.

About 1895 the Delta Metal Co. developed a simple 500-ton hydraulic press, a horizontal rod type powered by a direct head unit (multiple plunger pump). About 1897, Mr. Charles F. Brooker, then president of the Coe Brass Mfg. Co. of Torrington and Ansonia, Conn., while visiting in England, saw the attempts at brass extrusion and arranged the purchase of a duplicate of the original press. This second extruder was delivered and in experimental operation in 1900. By 1905 the commercial extrusion of leaded screw-machine brass rods and shapes was established. This early accomplishment superceded the costly practice of 15 pass cold rolling of castings to base sizes of rod.

To extend the field of operations to richer copper mixtures it was necessary to construct much more powerful extruders and pumps, and to improve the heating of cast billets. Initially soft coal was used for fuel, then oil. Today, gas with controlled atmospheres to prevent oxidation gives best results.

From 1905 to about 1915 several rod extruders were under development in eastern and Naugatuck Valley mills. Press capacities increased from the initial 500 tons to an average of about 2000 tons. This meant that where 5 and 6 in. diam billets netted 100 lb per cycle with a 500-ton extruder, 250 to 350 lb could be realized from 7 to 8 in. diam billets when using the average 2000-ton press. With the development of larger presses came better proportioned billets, with ratios of diameter to length never more than 1:3. Also multiple hole dies (three outlets, triangularly arranged), proved most beneficial to uniform flow and life of 12 to 18 pct tungsten steel die blanks. Scalping of billets during extrusion also developed in the early years. This consisted of using pressure disks, commonly known as *dummies*, of a smaller diameter than the container bore, resulting in temporarily freezing the shell or skin of the cast billet against the container liner. By so doing much of the piping or coring tendencies were minimized and the life of dummies increased. Preforging of billets in the container prior to extrusion was likewise a deterrent to piping and a means of densifying heated metal and unifying grain size.

This experimental period covered practically all of the malleable alloys of copper, over the range of heats for plasticity of 1400° to 1800°F. Modern rod extruders in brass mills having capacities from 1500 to 4000 tons and operating on rod or strip base materials can average, on common sizes and at lower temperatures, from 20 to 50 cycles or pushes per hr, netting roughly from 5000 to 25,000 lb hourly. Press or extrusion scrap can be held between 10 and 25 pct with the employment of modern and amply powered equipment. Today, a 4000-ton extruder applied exclusively to commercial brass can accommodate billets from 10 to 16 in. diam and 30 to 36 in. long and deliver bars or coils up to 2000 lb in weight. As much as 35,000 lb per hr can be produced and extrusion scrap is below 10 pct.

Extruded materials intelligently processed are of high quality, and develop fine, short-grained, manufactured products. This is because of the absence of oxide inclusions or seams, spills, and directional properties more common to base and finished goods obtained from the rolling of castings. For example, it is a rarity to find a cracked rivet or bolt head coming from extruded base stock, or any sign of *earing* in the drawing of cups from extruded strip.

Simplification of seamless tube manufacture was in the mind of every brass mill executive, and as early as 1910 to 1915, several unsuccessful attempts had been made to construct double-actioned presses

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or extruders which would deliver concentric base tube shells. Eccentricity in tube sections (disparity in wall dimensions) has rightfully been named the "curse" of the tube business.

European engineers at that time appeared to have a better understanding of hydraulics and tube-making needs, and were offering vertical 600 to 1200 ton as well as larger 2750 ton horizontal *Universal* type presses. While these were investigated, World War I broke out and it was not until about 1925 that the brass industry ordered its first *Universal* extruder from Germany. The press was under the name of Schloemann, and was a 1500-ton horizontal.

The Loewy Brothers, one-time exponents of the Schloemann Engineering Co., Duesseldorf, and their staff of engineers completely redesigned and set up the standards for the entire line of modern extruders during the late 1930's. Fig. 1 is a 2400-ton hydraulic Loewy extrusion press for tubes.

To appreciate the value of the extrusion process, it should be mentioned that in 1895 the common source of I.P.S. brass tubing for plumbing was sand-cored tubular castings in approximately 4 in. OD, ½ in. wall thickness, and 4 to 6 ft long. This cast material being subjected to 10 or 12 push-bench and draw-bench reductions and as many between anneals and cleanings could cause the average trip through the mill to consume 10 days to two weeks time. Today, by extrusion, common high brass tube shells 2x3/16 in. and 30 to 50 ft long capable of being finished in one or two cold operations (usually cold drawing) can be completely processed in 2 or 3 days. Some classes of brass are incapable of being hot worked by the *Mannesman* piercing and rolling method, by which copper billets 3 in. diam and 4 ft long can be converted into tube shells 3 in. OD, ¼ to 5/16 in. walls and 10 to 12 ft long in one operation and on a time cycle comparable to extrusion.

As general information to prospective users of *Universal* extruders on average brass to copper base tube shells, a 2250-ton *Loewy* is capable of 2,000,000 lb monthly. This is on a double 10-hr shift consuming 57,539 man hr:

Man Hr per 1000 Lb	2.7
Lb per Man Hr	377.0
Lb per Machine Hr	4070.0
Pct of Machine Scrap	20 or less

(including shells cut to weight and length)

For miscellaneous classes of mill work, a *Universal* extruder of a horizontal type and around 3000-ton capacity would be suitable.

With such a choice should go a suitable power plant (pumps and accumulators of the air bottle type); and a well engineered billet heater that is gas fired and equipped with burners to control atmospheres anywhere from neutral to reducing. This heater specification is most important when contemplating extrusion of any metal susceptible to and damaged by oxidation (copper and alloys, nickel and alloys, steels all classes).

Vertical extruders have a natural centering advantage when producing short tubes, and demand a little less labor, but they have several disadvantages. Primarily, verticals are satisfactory only in capacities of less than 1000 tons. Maintenance is difficult when heavier hydraulic extrusion presses are put on end because of the limited area of foundations and support. Larger extruders on end demand considerable head room, and interfere with crane operation and service to the press.

Verticals applied to tube extrusion are limited to short lengths of products; all of which must be delivered vertically to a pit or the floor below and around a corner or 90° angle. On the other hand a horizontal extruder with an overall length of 40 to 50 ft is constructed on substantial foundations and supplied with bearing plates and adjustments including takeups for simplified maintenance. Any experienced operator can obtain just as good concentricity in tube products with a properly designed horizontal as with a similarly constructed vertical. If a *Universal* or double-actioned press is regularly employed as a general utility extruder (straight or coiled rods, base strip, and tube shells) and a goodly portion of its schedule is occupied on solid sections, a thorough mechanical checkup is highly essential before switching to tube production. Adjustments and replacements should be made at that time of features governing the concentricity of tube shells.

Fig. 2 represents a sectionalized view of a *Loewy* standard double-actioned tube extruder of the *Universal* horizontal type. The only difference between the double-action machine and the single-action machine is the elimination of the piercing cylinder and plunger, and the use of a solid ram instead of the hollow ram shown, through which the piercing mandrel operates. Water for hydraulic pressure is supplied usually by a pump and accumulator system at pressures from 3000 to 5000 psi. Also a low-pressure prefilling system is generally used for idle stroking of the ram, in order to conserve high-pressure water. Fig. 3 is a diagram of extrusion dies.

Clark and Cotter[1] gave average results of a number of tests made during commercial operation, mainly on a 2200 to 2750-ton tube press used to extrude rod. As it was necessary to throttle connections to gages to protect the Bourdon tubes, the

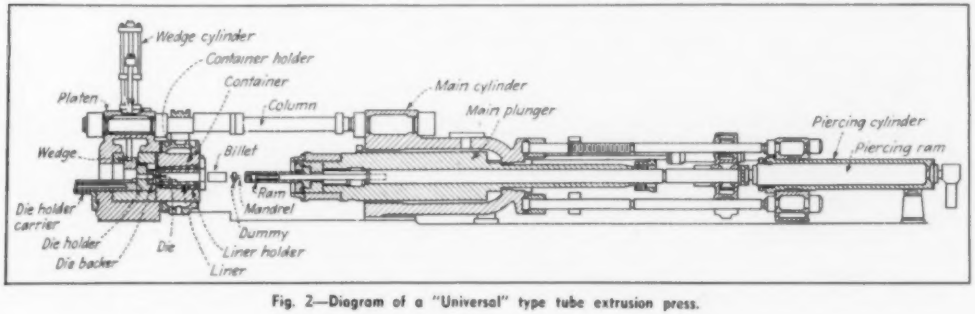


Fig. 2—Diagram of a "Universal" type tube extrusion press.

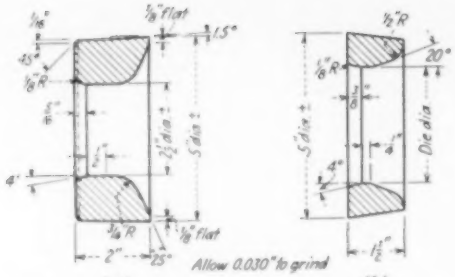


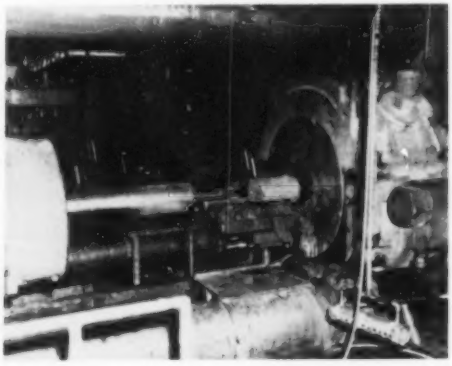
Fig. 3—Extrusion dies of copper-base alloy: (a) tube, (b) rod.

pressures recorded were subject to slight error. There are so many other variables in the operation, such as length of time between the withdrawal of the billet from the furnace and the application of pressure in the extrusion container, copper content, container temperature, die temperature, and dummy temperature, close uniformity in readings taken from successive extrusions cannot be expected.

The pressures recorded varied as much as 10 pct above or below the average given in the table, and when it is noted that 25° variation in cartridge brass would result in 10 pct apparent resistance to deformation, this is not surprising. In screw machine rod, variation in copper content of 1.5 pct will show about 10 pct variation in resistance at a given temperature.

In most modern machines, extrusion speed is controlled by the main operating valve and an adjustable throttle valve. The latter can be set to control roughly the extrusion speed. In commercial practice, it is necessary to complete extrusion with sufficient rapidity to prevent excessive temperature drop in the billet through transfer of heat through the dummy, container liner, and die face. Frequently the operator sets the throttle valve at a predetermined opening, and opens the main valve wide when extrusion starts. If the billet is a little hotter or its copper content a little lower than usual, extrusion will be more rapid until there is a balance between pressure and extrusion speed. The pressure drops because of the speed of flow through the throttle valve to the main plunger. The experienced operator soon can determine the best billet temperature and speed of extrusion for any given billet analysis, length, and die area, and will vary these somewhat, depending upon whether he is starting up in the morning with a cold container liner or running under normal operating conditions. Fig. 4 shows the hot billet in front of the container before extrusion.

Fig. 4—Hot billet in front of container before extrusion.



Multiple-hole extrusion is resorted to where the $(D/d)^2$ and (L/D) are too large to permit successful extrusion of a single small section. The pressure required in multiple extrusion is somewhat greater than with a single hole of area equal to those of the multiple dies, because of greater surface area of the multiple dies, but not in proportion to the benefit derived from the reduction of pressure caused by reducing log. $(D/d)^2$ to log. $(D/2d)^2$ or log. $(D/3d)^2$.

Clark and Cotter[1] also gave data obtained from the tube extrusion of four different alloys. Admiralty metal has resistance to hot-working comparable to the 69 Cu-31 Zn mixture used in rods. This tube extrusion shows a slightly higher minimum extrusion pressure than in average rod extrusion, and a somewhat lower maximum, the latter because the billet length is less in all cases than in rod extrusion.

It is to be expected that the basic pressure in tube extrusion would be slightly higher because of the increase in chilling of the billet by the piercing mandrel and the increased frictional resistance caused by the mandrel surface during extrusion.

Also, the speeds were somewhat greater in the tube extrusion than in that of the rod. It is desirable to extrude tubing faster than rod to keep the contact time between the piercing mandrel and the billet as short as possible so that the mandrel will not heat sufficiently to reduce its tensile strength.

The piercing mandrels are made from chromium-tungsten or chromium-tungsten-molybdenum steel with the two latter elements kept sufficiently low to prevent cracking when water is applied for cooling between extrusions. When alloys require higher extrusion temperatures or longer contact with the heated billet, it may be necessary to use mandrels with higher tungsten and chromium content, and oil cooling may be necessary between extrusions. This is particularly true in vertical extrusion in which small billets and small-diameter mandrels, from 1 to 1½ in. are used in the extrusion of small-size tubing.

In the early days of extrusion, grades of steel for tools interposed a limit on the copper content of alloys that could be extruded, and the operation was confined to the Muntz metal group containing from 56 to 61 pct copper. As alloy steels were developed and heat treatments perfected, it became possible to extrude alloys having greater resistance to hot-working, until today it is possible to utilize pressures in extrusion of more than 100,000 psi of ram pressure. With the harder alloys, greater care must be taken in the entire operation. Hot-working tools for handling higher temperatures and pressures are subject to cracking if local stresses of too great magnitude are introduced by sudden application of heat when in the cold state or too rapid chilling when hot. Therefore, these tools must be slowly preheated and maintained at a suitable temperature at all times during their use. Preheating also limits the amount of heat absorbed from the billet and prevents lowering billet temperature during extrusion to the point where the pressure of the main ram is insufficient to complete the operation.

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Statistical Analysis of Blast Furnace Production Data

by D. S. Leckie

THE functioning of a blast furnace is undoubtedly one of industry's most complicated metallurgical processes. It is made so by the extremely large number of variables attendant upon the operation; variables in the burden materials, in construction of the furnace and its auxiliary equipment and the operator's manipulation thereof, and in the product and byproducts of the process. Recent trends toward larger furnaces, steel plant demands for higher quality product, and gradual changes of quality in raw materials, with the resultant working of an increasing amount of both less desirable deposits as well as new deposits, have increased the problems of the operators by adding still other new variables. A classic example is the complications resulting from the use of ores bearing titanium oxide.

The furnace operator has been aided by the research experimenter either in the laboratory or on the job. Orthodox methods of research into the situations involving several variables have usually been to hold all variables constant but one, and to study effects of controlling variations for that one variable. Unfortunately, this often does not work too well for the blast furnace because of the extensive number of variables involved. Not only do these numerous variables have variations, but their innumerable combinations have variations and it becomes an insuperable job to control them laboratory-wise. For this reason the modern experimenter has been driven to the furnace and the furnace thus becomes its own laboratory. This is all to the good, because, while a laboratory technician, an experimenter, and even occasionally an operator can be fooled, a blast furnace cannot. Frequently, in the actual operation of a furnace when some one variable changes, the operator makes compensating changes, and thus destroys the *anticipated* effect of relationships. The operator is charged with smooth and economical operations. If the furnace is operating satisfactorily, he is loath to make changes; if it is *sick*, he wants to restore normal operations as quickly as possible. In all this he is guided by experience and know-how developed from his own operations and those of others. Human nature being what it is, the operator is sure to remember the things that worked but is prone to forget the times when that same corrective action failed to produce anticipated results.

In the study of blast furnace operations, true interest lies in the *cause* and *effect* relationships. The operator wants to know how to control variables so as to produce a desired effect or result. It is unfortunate that a study of a selected relationship within a complex system of inter-relationships, such as in the blast furnace, can easily lead to incorrect and misleading conclusions. This is because the relationship studied is only the apparent and not the true relationship. The human mind simply cannot store up all the complexities of this operating system, nor can it separate unaided the cause and effect relationships from those which are purely fortuitous.

The problem is one of analyzing the data produced by the operation; data such as is customarily tabulated daily, hourly, or otherwise. Two well known though perhaps not widely used statistical techniques designed specifically to assist in evaluating such a complex process are called Analysis of Variance and Multiple Correlation. While they have assets of extensive value, they also have liabilities. Not the least of these liabilities is the extreme ponderousness of the arithmetic involved. Because of this fact, plus the lack of trained personnel and the lack of competent interpretation of results, acceptance of the use of these techniques has been slow. Fortunately, the burden of this initial factor recently has been lightened by the design and construction of certain calculating equipment.

As a prelude to a correlation analysis of blast furnace data the routine recorded data on daily operations of a specific furnace were accumulated on special tabulation forms. This included daily data on burden materials, certain operating variables, production, iron and slag analyses, etc., and covered an operating period of the first three months in 1949. Purely from a standpoint of mechanical mathematics all the recognized variables on which data were accumulated could not be used. Because of the unreliability of data from any one day, three-day averages were calculated. This has been found the best method for keeping the erratic individual values from unduly affecting these studies. These averages were then arranged in columns, suitably coded for easier manipulation.

Modern mechanics comes into the picture in the form of International Business Machines equipment, the use of which is becoming more and more familiar. Data were punched into tabulating cards and suitably treated for the determination of several key values, such as the sums of each column of data, the sums of the squares of each individual value in each given column, and the sums of the products of the values in each column and its corresponding value in each of the other columns. For the problem at hand, such computations would require about six days for an experienced operator to perform on the conventional calculating machine. The work can be done on I. B. M. equipment in 6 hr or less.

Following some supplementary computations, with which work is also much reduced by the use of fully automatic calculating machines, the major job is ready for calculation; this is the solution of a series of simultaneous equations, one such equation for each

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variable selected for study. This is another tedious mathematical job and would require four or five days to complete on conventional calculators. Use was made of the Consolidated Computer, a highly complex electrical machine designed for just such work, and the work load was reduced to 3 or 4 hr.

The result of this calculation is a series of numbers of four digits each, one such number for each of the variables in the problem. These numbers are used to express the relationships existing between the several variables selected as causes and the one selected as effect. Some supplementary calculating machine work developed other pertinent factors of vital interest to the practical interpretations. This step is fundamental and has been the major cause for the doubt and suspicion which operators have experienced as a result of this type of analysis. It must be remembered that the statistician can interpret only mathematical factors; the skill of someone well versed in the operation being analyzed must be combined with that of the statistician if a sensible and practical interpretation is to result. Unless the interpretation makes sense to the operator, he is naturally skeptical and derisive.

Every blast furnace operator is interested in anything that lies within his control which will increase production or decrease coke rates. One factor that was of vital interest was the effect of varying top pressures on these two items. The burden consisted of five or six different ores, 25 to 30 pct sinter, 5 to 10 pct scale, about 5 pct openhearth slag and 2 to 3 pct scrap. Wind rates were from 56,000 to 65,000 cfm (averaging about 63,000), top pressures ran from about 4 to 10 lb, and daily production ranged from 860 to 1,150 tons of basic iron. This last is quite a variation and the question of cause arises.

The first important information from the calculation is that of all the variation that existed in the production, from day to day, 72 pct has been accounted for by the variables that were selected for inclusion in the study. It has been mentioned that inclusion of all known variables was impossible; those believed to be most important in affecting production were selected. What was the specific net effect of varying top pressure, alone and by itself, on production? The answer, from the analysis, was that production increased from its average value of 985 tons per day, for each increase of 1 lb of top pressure above the average value of 7½ lb. Decreasing top pressure caused a like decrease in production. Similarly, the coke rate decreased 48 lb per ton of iron from its average value of 1685 lb for each increase of 1 lb of top pressure above the average value of 7½ lb. On the other hand, as top pressure decreased, coke rates increased by a like amount.

The conventional and much simplified method of studying these relationships would be merely to compare, for example, coke rate data with corresponding top pressure data. A little thought will show that such a method of analysis is almost futile. There are many other factors at work concurrently with top pressure which importantly affect coke rates. Each of these factors may, and usually does, vary at the same time that the top pressure is varying. It could be a false assumption to say that an increase in coke rate accompanied by a decrease in top pressure was caused by that decrease. As a matter of record the simple relationship, or correlation, of top pressure and coke rate data showed a decrease of but 9 lb in coke rate for each 1 lb increase in top pressure. The *multiple correlation* method gives the true value of this relationship; a 48-lb decrease in coke rate for each 1-lb increase in top pressure.

Herein lies the chief value of the multiple correlation, where several factors, all of which might have an effect on coke rate, are considered simultaneously. It is then possible by mathematics to evaluate the true effect exerted by any one of the variables, independent of simultaneous variations in any or all of the others, on coke rate. Thus the interreactions, of which a fantastic number are involved in blast furnace operations, are eliminated from the conclusions and interpretations. It must be stressed that any conclusions from such a multiple correlation are valid only over the range of the data analyzed; extrapolation into other areas is hazardous.

Additional evidence is provided from the calculations as to the degree of confidence that can be had in the results. For example, there is a 98 pct assurance that an increase in production of from 12 to 26 tons of iron per day, with a probable value of 19 tons per day, resulted from an increase of each pound of top pressure throughout the range of 4 to 10 lb, and this effective increase in tonnage is totally irrespective of any other factors which also exerted their effects upon tonnage. This range of error within which the prediction may lie, and the degree of confidence that can be had in such prediction, are powerful tools.

There are three separate and distinct phases, and hence problems, associated with such studies. First is the selection and suitable tabulation of the data (and here a word of caution is in order with respect to obtaining factual data). Second is the systematizing and streamlining of the calculations. Third is the interpretation of results. It is possible, with the aid of I. B. M. equipment, fully automatic calculating machines and the Consolidated Computer, to systematize this entire operation and thus solve a large number of continuing problems that, until recently, could not be begun because of the incomprehensible volume of work entailed.

These new tools can be adapted readily to a multiple furnace shop or a multiple plant organization. Prepared data sheets will be filled in daily by blast furnace clerical personnel, or existing recorded data, as selected, may be utilized. Data will then be transferred to I. B. M. punched cards and filed. When a particular survey area or period is selected, the appropriate punched cards will be processed, according to routine instructions, by the I. B. M. service department. These results will then go to the statistical department where the correlation coefficients are computed on automatic calculators, the equations set up and solved by the Consolidated Computer and the supplemental index figures calculated. A joint session between statistical and operating departments then follows for interpretation. All of this can be accomplished in 3 or 4 days' for even the complicated problems; the simpler ones will require much less.

It must be emphasized that by no possible stretch of the imagination can mechanized mathematics replace the experience, skill and know-how of the operator; let no operator have the least apprehension and let no statistician have illusions of grandeur. Many of the large crude oil cracking operations are materially aided by almost hourly analyses of operations data by the methods and systems described. Sets of constants are developed and deviations therefrom, when analyzed, indicate the corrective action.

Metallurgy of Cobalt Production From Cupriferous Pyrite

by Sanai Nakabe

Japanese wartime economy demanded domestic cobalt production. This paper describes a process operated for two years at the Besshi mine and smelter on extremely low grade (0.1 pct Co) pyrite concentrates obtained from copper ore. The steps in the process were roasting, leaching, precipitation, reduction fusion to crude cobalt, and finally refining by electrolysis to 99+ pct.

COBALT ore deposits in Japan are all small and of poor grade. In the past, a small amount of cobalt has been produced from the best portions of a few of these deposits, and very little production is expected in the future. In addition to these lean cobalt ores, cobalt is present in the cupriferous pyrite which is fairly abundant although of low grade, as is shown in Table I. Considerable cobalt is expected from these deposits because of their extent.

Cobalt cannot be exclusively recovered economically from ore of this type; however, if means could be devised to recover it as a byproduct of copper production, a fairly large production at reasonable cost could be expected from Japanese sources. It was along this line that the research work was done.

Table I. Some Examples of Cobalt Content of Japanese Cupriferous Pyrite

Mine	Co, Pct	Cu, Pct	Fe, Pct	S, Pct
Ismori	0.11	1.74	39.52	44.25
Shirataki	0.05	1.60	44.51	50.77
Kotsu	0.22	2.80	42.51	49.09
Chihara	0.04	19.89	29.75	33.75
Kune	0.19	8.64	40.29	45.36
Motoyasu	0.10	3.47	44.18	50.34
Yanahara	Trace	0.55	45.51	51.47
Makimine	0.17	5.40	42.57	46.10
Sazare	0.04	5.49	39.96	45.69
Besshi	0.10	4.72	40.84	45.55

Selection of Suitable Process

The process for extracting cobalt differs from ore to ore according to their composition. The difficulty in cobalt metallurgy arises from the fact that chemically cobalt resembles many such common metals as Mn, Fe, Ni, Cu, and Zn, associated with it in the ores. In the present case the most serious difficulties were:

1—Extremely low grade ore, 0.1 pct Co.

2—The large proportion of iron accompanying cobalt and its close similarity in chemical behavior.

3—The fairly large proportion of zinc and manganese and their chemical similarity to cobalt.

The recovery of cobalt oxide as a byproduct of the hydrometallurgy of copper had been attempted in Japan but was stopped after a short period because it proved uneconomical. The literature disclosed no method for the recovery of cobalt from cobaltiferous copper pyrite and it was therefore necessary to devise a new process.

The following basic principles were considered in selecting the process:

1—A major alteration in copper production methods should not be necessary.

2—The first step should be the extraction of cobalt leaving the large quantity of iron unaffected. For this purpose wet metallurgy would be preferred.

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Table II. Distribution of Cobalt to Intermediates in Copper Smelting

	Cu, Pct	Fe, Pct	Co, Pct	S, Pct	Co Quantity
Crude ore	1.17	19.16	0.03	9.98	100
Copper concentrate	10.36	34.51	0.10	36.47	27
Pyrite concentrate	0.32	41.52	0.10	45.05	30
Flotation tailing	0.09	13.05	0.01	2.36	26
Blast furnace matte	35	40	0.3	23	20
Blast furnace slag	0.3	35	0.06		35
Converter slag	2	35	0.4		20
Blister copper	98		0.002		0.1

3—A crude precipitate of cobalt would be satisfactory in order to avoid a large expenditure in chemically treating a huge volume of leach solution to obtain a pure precipitate.

4—The crude cobalt precipitate would be further refined. It would not matter if the process became somewhat complicated at this point because the quantity of material for treatment would be decreased markedly.

Selection of Direct Raw Material

As the raw material it was first necessary to select an intermediate product from the copper extraction process. Four were selected, namely, pyrite concentrate from the flotation, matte from the blast furnace, slag from the same, and slag from the converter.

Three different processes were devised for treating concentrate, matte, and slag. The first one for treating the concentrate proved to be best suited for the circumstances at Besshi mine and the Japanese wartime economy. This process was operated on a plant scale and will be reported here, but the other two were not developed to plant size although they proved to be valuable in those cases where somewhat more cobalt is contained in the raw material in copper smelting. The compositions of several intermediate products at the Besshi smelter are shown in Table II. In order to make it pay it is desirable that a process for treating a poor raw material should have some extra merits in addition to the principal one which, in this case, aims at cobalt recovery. By treating iron concentrate, a quantity of copper would be recovered and, at the same time, the quality of the leached residue, by the elimination of copper, would be enhanced.

Flotation

Usually no distinct cobalt mineral is identified in the ores and it is supposed that cobalt exists in solid solution in the pyrite crystal, displacing some of the iron atoms. Whether there is any difference in cobalt content between chalcopyrite and iron pyrite is open to question. In the case of the Besshi ore there is little difference according to the analyses of the two kinds of concentrate produced at the flotation mill, Table III. It was concluded therefore that no change in the process of flotation was necessary and both concentrates must be treated separately for cobalt production.

Table III. Distribution of Cobalt by Flotation

	Co, Pct	Cu, Pct	Fe, Pct	S, Pct	Production Ratio, Pct	$CuFeS_2$, Calculated	FeS_2, Calculated
Feed ore	0.03	1.17	19.16	9.98	100	3.4	16.5
Copper concentrate	0.10	10.36	34.51	36.47	11	29.9	48.7
Pyrite concentrate	0.10	0.32	41.52	45.07	9	0.9	84.0
Tailing	0.01	0.09	13.05	2.36	80	0.5	4.2

Table IV. Successive Change in Roasting

Hearth No.	Residual S, Pct	Water-Soluble Ingredients			
		Co, Pct	Cu, Pct	Fe, Pct	S, Pct
3	27.45	0.010	0.040	0.143	0.77
4	20.62	0.012	0.058	0.402	0.96
5	5.18	0.040	0.168	0.347	1.24
6	3.07	0.053	0.245	0.782	2.45
7	1.90	0.068	0.291	0.468	1.56
8	1.81	0.067	0.283	0.226	1.36

Roasting

Various methods were examined to render cobalt in pyrite soluble in water or dilute acid, and it was finally decided that an oxidizing roast was the best practical method if sufficient attention was paid to operation. Roasting for sulphuric acid production needs no special regulation, but for cobalt extraction careful control in roasting is necessary. The most important factor in roasting regulation is the temperature control which will be explained.

Practically all of the soluble cobalt in the cinder proved to be cobalt sulphate and not oxide. This was true with acid leaching as well as with water leaching not only for oxidizing roasts but for all the roasting methods tried. Therefore, it was most desirable to convert as much into sulphate as possible. Most of the cobalt sulphate was formed near the final roasting stage according to the numerical order of the following equations. An example of the successive change is given in Table IV which shows analyses of samples taken from each hearth of a Herreshof-type roaster. The diameter of each of the eight hearths was 9 ft 6 in.

$$FeS_2 \rightarrow FeS + S \quad [1]$$

$$FeS + 1\tfrac{1}{2}O_2 \rightarrow FeO + SO_2 \quad [2]$$
$$FeS + 2O_2 \rightarrow FeSO_4$$

$$CoS + 2O_2 \rightarrow CoSO_4 \quad [3]$$
$$2FeSO_4 \rightarrow Fe_2O_3 + 2SO_2 + \tfrac{1}{2}O_2$$

Cobalt sulphate was not formed in the rapid oxidation of pyrite resulting in a black cinder. One of

Table V. Ferrite Formation

Heating Temperature, °C	Water-Soluble Quantities		H_2SO_4 Leach of Residue,	Final Residue,
	Co, G	Fe, G	Co, G	Co, G
500	0.116	0.001	0.001	0.006
550	0.111	Trace	Trace	0.010
600	0.059	Trace	Trace	0.067
650	0.046	0.001	0.001	0.084
700	Trace	Trace	Trace	0.123

Table VI. Lack of Ferrite Formation

Heating Temperature, °C	Water-Soluble Quantities		Solubility of Co, Pct
	Co, G	Fe, G	
500	0.122	0.003	90
550	0.100	0.003	74
600	0.105	0.004	78
650	0.100	0.002	81
700	0.095	0.002	70

the necessary conditions, therefore, was slow oxidation through control of the temperature or air supply. This resulted in a brown cinder. Another factor was the formation of ferrite. In the presence of ferric oxide, ferrite formation begins at about 600°C and increases as the temperature rises. However, in the presence of ferrous oxide and no ferric oxide, ferrite does not form even at the high temperature of 800°C. Table V shows the formation of ferrite when a finely ground mixture of 1.5 g of Fe_2O_3 and 1.5 g of $CoSO_4 \cdot 7H_2O$ was heated for 1 hr at the indicated temperatures. The results are shown of leaching 1 g of the product in water and further leaching the residue in boiling 2 pct H_2SO_4. Table VI indicates the absence of ferrite formation when a similar experiment was conducted using ferrous oxide instead of ferric oxide.

The optimum roasting temperature for cobalt sulphate formation was found to be about 550°C. This was determined experimentally, Table VII, using a small electrically heated rotary kiln. The rate of formation of cobalt sulphate is low and many hours are required for a satisfactory conversion. This is shown in Table VIII which summarizes the best results obtained by leaching cinder from different furnaces. Thermal decomposition of cobalt sulphate is not appreciable at temperatures below 750° to 850°C.

In practice a Herreshof-type furnace was found best suited for the purpose. The charging rate and the air supply must be so controlled as to obtain a gradual and sufficient oxidation, and at least two of the upper hearths must be maintained at 500° to 600°C. The maximum temperature of the upper hearths usually went over 800°C but this was not detrimental to cobalt sulphate formation in the absence of Fe_2O_3. The conversion was about 70 pct (soluble Co 0.09 pct) under good conditions, but fell below 30 pct with poor regulation. The ore particles swelled, becoming very porous, which had a favorable effect on leaching, Table IX. The moistures of cakes obtained by vacuum filtration of slurries are shown to give a rough idea of the porosity of the particles.

Leaching

The purpose of leaching is to dissolve cobalt and copper, leaving all of the iron undissolved in the residue. The only economical solvents, in view of the poor grade of the raw material, would be water or dilute acid. It was concluded, after thorough experimenting, that even dilute acid was not suitable because, although it gave slightly better cobalt and copper extraction, it dissolved considerably more iron than was the case with water leaching. Grinding, heat, and increased leaching time had little effect, as shown in Tables X through XIV. Sea water could also be used, Table XV.

Cinder was classified into three parts as indicated in Table XIV, and half of each ground to —100 mesh. Both halves were water-leached for comparison.

The data in Tables X to XV lead to the conclusion that the leaching is a very simple problem, but in practice it is very important to wash the residue efficiently in order to obtain simultaneously high extraction and high concentration of the leach solution. Continuous countercurrent decantation was adopted easily because of the fine particle size. High porosity of the cinder was not conducive to good washing because in a thickener the settled material contains as much as 40 to 50 pct water. The analysis of the leach solution was as follows: Co, 0.2 to 0.3; Cu, 0.5 to 1.5; Fe, 0.3 to 1.5; Zn, 0.3 to 0.6; Mn, 0.1 to 0.2 g per liter.

Treatment of Solution in General

Recovery of pure cobalt oxide from such a solution is difficult for a variety of reasons. The cobalt concentration is small and any prior removal of copper and iron by any of the usual methods would still leave enough behind to seriously contaminate the cobalt when ultimately recovered. Moreover, extreme dilution made necessary the treatment of such huge quantities of solution that production cost inevitably would be high in the case of a complicated flowsheet involving heating, filtration, reagents, etc. Zinc and manganese are so close to cobalt in chem-

Table VII. Selection of Roasting Temperature

Temperature, °C	Water Extract		
	Co, Pct	Cu, Pct	Fe, Pct
450	0.060	0.25	7.95
500	0.067	0.40	4.05
550	0.096	0.28	0.27
600	0.083	0.10	0.01
650	0.027	0.03	0.01
700	0.006	0.01	Trace

Table VIII. The Effect of Roasting Time

Type of Furnace	Diameter Dimension	No. of Hearths	Capacity, Tons per Day	Stay, Hr	Color of Cinder	Water Leaching		
						Co, Pct	Cu, Pct	Fe, Pct
Herreshof	10 ft 6 in.	8	14.4	12	Brown	0.10	0.27	0.15
Herreshof	15 ft 10 in.	6	7.2	8	Brown	0.07	0.15	0.26
Herreshof	3 ft 6 in.	10	0.6	5	Brown	0.06	0.24	0.22
Rotary kiln	294 x 31m		45	2.5	Black	Nil	0.03	0.02

Table IX. Swelling of Ore Particle by Roasting

	Mesh						Moisture, Pct
	+10, Pct	+28, Pct	+48, Pct	+100, Pct	+200, Pct	—200, Pct	
Pyrite concentrate	0.3	0.0	4.8	2.1	16.6	76.5	10
Cinder	1.3	2.2	4.3	11.9	32.9	47.5	32

Table X. Comparison of Water and Acid Leaching*

	Co, Pct	Cu, Pct	Fe, Pct	Zn, Pct
H_2O	0.072	0.21	0.11	0.27
2 pct H_2SO_4	0.076	0.35	1.10	0.39

* Leaching at 80°C for 5 min.

Table XI. Effect of Temperature and Acid Concentration in Leaching*

Solvent	Temperature, °C	Co, Pct	Cu, Pct	Fe, Pct
H_2O	60	0.069	0.15	0.08
0.5 pct H_2SO_4	30	0.070	0.19	0.32
0.5 pct H_2SO_4	60	0.068	0.23	0.78
2 pct H_2SO_4	60	0.071	0.27	1.63
2 pct H_2SO_4	90	0.073	0.30	2.80

* Leaching for 30 min.

Table XII. Effect of Time in Water Leaching*

Time, Min	Co, G	Cu, G	Fe, G
5	0.0214	0.0883	0.0200
10	0.0212	0.0893	0.0211
20	0.0221	0.0897	0.0266
40	0.0223	0.0901	0.0191

* 50 g ore was agitated with 100 g water. 50 cc extract analyzed.

Table XIII. Effect of Particle Size on Leaching*

Mesh	Co, Pct	Cu, Pct	Fe, Pct
+35	0.048	0.33	0.14
−35 + 65	0.055	0.33	0.15
−65 + 100	0.058	0.36	0.08
−100 + 150	0.053	0.35	0.08
−150 + 200	0.050	0.31	0.11

* Water leaching at 60° for 30 min.

ical behavior that their elimination or separation is difficult even in the case of chemical analysis. No known hydrometallurgical method was entirely satisfactory from a technical and economic viewpoint.

It was decided finally to treat the leach solution to obtain a cobalt precipitate after eliminating only those easily separable elements to such a degree as could be accomplished easily. This means that the solution treatment would be a mere concentrating process differing from the usual hydrometallurgical process in which refining is accomplished.

The simplest operation in each step in the process was chosen; heat was not involved, separation of the bulk of the liquid from any precipitate was by decantation, and the whole was operated continuously so that huge volumes of liquid could be passed through small equipment. Chemical reactions were selected that could be adapted to such a flowsheet. Equipment consisted of small agitation tanks for reagents, one or two medium tanks for completion of reactions, a large Dorr thickener for decantation, and filter presses to take only thickened slurry when necessary. Such cheap and simple steps were arranged for each individual reaction.

Elimination of Copper and Iron

The simplicity of the equipment referred to above required a precipitate that would settle easily at room temperature, namely one of fairly large particle size. To achieve this in minimum time it was necessary to consider the solubility product of the precipitate to be formed. Copper sulphide or ferric hydroxide, for example, are not suitable because their solubility products are too small to allow the precipitates to coagulate or grow to larger particles. Of course coagulation could be accomplished by applying heat and controlling the pH, but these procedures were out of the question. Since, on the other hand, a high solubility product meant incomplete elimination, there was no alternative but to choose precipitates having a moderate solubility product. In addition the solubility product of the copper or iron precipitate must be low in comparison with that of the cobalt compound present to allow separation. These requirements led to the selection of eliminating copper as the hydroxide.

Regarding the iron, there were many reasons for precipitating it as the hydroxide. Iron was present in the solution as ferrous sulphate. The solubility product of ferric hydroxide was too low, as mentioned earlier, and any excess of reagent used for oxidizing ferrous iron is apt to precipitate $Co(OH)_2$ together with the iron. Furthermore, ferric hydroxide has a greater tendency to drag down cobalt by occlusion. In the process iron and copper were successfully eliminated simultaneously as $Fe(OH)_3$ and $Cu(OH)_2$.

Table XVI shows the results of experiments in which varying amounts of soda ash were used for precipitation.

The following comments are important from the standpoint of practical operation:

1—Loss of cobalt is closely related to the excessive elimination of copper from solution.

2—Loss of cobalt increases with increase of iron in the original solution.

3—The elimination of copper and iron must be made in two stages in order to diminish their concentrations below 0.01 g per liter, which means the remaining copper or iron must be less than 1/20th of the cobalt, thus limiting the loss of cobalt to a few percent.

4—The precipitate from the second stage contains considerable cobalt which must be recovered. To do this the thickened slurry is agitated with the original solution in the first agitator where the cobalt is dissolved, Table XVII, according to the following reaction:

$$Co(OH)_{2\ etc.} + Cu\,SO_4 \rightarrow CoSO_4 + Cu(OH)_{2\ etc.}$$

This simple method is very effective in saving reagents because the second stage precipitate is not only leached without consuming any particular reagents, but also serves as a base for precipitating copper from the original solution.

Composition of original solution added: Cu 1.05, Co 0.32, Fe 0.05 g per liter. To 100 cc of second copper precipitate slurry, the sulphuric acid or original solution was added, agitated for 30 min at room temperature and filtered. Before treatment 100 cc of second copper precipitate contained the following: Dry material, 1.2 g; Co, 0.024 g; Cu, 0.394 g; and Fe, 0.003 g.

5—Soda ash additions were controlled using the remaining $CuSO_4$ in the mother liquor as indicator, 0.1 g per liter in the first stage and 0.01 g per liter in the second. The copper present was determined colorimetrically by the operator. In actual operation

Table XIV. Effect of Grinding on Leaching

Mesh	Grinding	Water Extraction Co, Pct	Cu, Pct	Fe, Pct
+30	Not ground	0.030	0.11	0.03
	Ground	0.030	0.10	0.10
−30 + 65	Not ground	0.027	0.13	0.05
	Ground	0.030	0.12	0.07
−65	Not ground	0.037	0.10	0.03
	Ground	0.037	0.10	0.03

Table XV. Comparison of Fresh and Sea Water for Leaching

Medium	Co, Pct	Cu, Pct	Fe, Pct
Distilled water	0.049	0.29	0.035
Aqueduct water	0.049	0.29	0.029
Sea water	0.048	0.26	0.006

the consumption of soda ash was about three times as much in the first stage as in the second.

6—The two-stage elimination of copper and iron was necessary also because, in spite of the large storage tank, the concentration of the feed solution varied considerably, 0.6 to 1.3 g per liter Cu, and with continuous treatment the addition of the correct amount of soda ash was impossible. Therefore, the first addition was purposely somewhat insufficient so that an unexpected decrease of copper in the feed solution would not result in an increase of cobalt in the precipitate. On the other hand, the second soda ash addition was maintained in excess so that a sudden increase of copper would not result in its incomplete elimination.

7—Soda ash was chosen as the precipitant although, from a reagent cost standpoint, milk of lime had some advantage. However, there are some disadvantages in using lime. Calcium sulphate crystallizes on the inner surfaces of pumps, pipes, and tanks making it necessary to use launders for solution transfer and to so place tanks that the transfer can be done by gravity decantation, thus eliminating pumps. Also if there are coarse particles of lime in the reagent there will be excessive precipitation of cobalt in their vicinity. It is preferable to use lime immediately after slaking.

8—The precipitate had the following analysis: Cu, 25 to 35 pct; Fe, 15 to 25 pct; Co, 0.2 to 0.3 pct; and Zn, 2 to 4 pct. This material could be charged into the blast furnace for copper recovery.

Precipitation of Cobalt

Cobalt was precipitated as cobaltic hydroxide using soda ash and chlorine. The chlorine which was purchased as a liquid was introduced into the solution as fine bubbles through porous porcelain tubes. In this process the separation of manganese was difficult since it precipitated as MnO_2 together with the cobalt. Part of the manganese was oxidized to permanganate, coloring the solution. Some zinc is also precipitated along with the cobalt.

Table XVI. Precipitation by Soda Addition*

Na_2CO_3, G	Precipitate					Filtrate		
	Co, Mg	Cu, Mg	Fe, Mg	Zn, Mg	Mn, Mg	Co, Mg	Cu, Mg	Fe, Mg
0.24	Trace	50	15	Trace	Trace	52	120	28
0.30	Trace	72	18	1	Trace	53	97	23
0.36	Trace	96	25	2	Trace	52	71	20
0.42	Trace	116	27	2	Trace	52	50	15
0.48	2.6	136	35	4	1	49	25	10
0.54	4.8	156	39	16	3	46	10	5
0.60	8.1	155	42	25	5	44	2	3

* Concentration of original solution: Co 0.26, Cu 0.84, Fe 0.22, Zn 0.36, Mn 0.03 g per liter.
Quantity of original solution: 200 cc.
Agitated for 1 hr at room temperature.
Na_2CO_3 was added as a 10 pct solution.

Table XVII. Dissolution of Cobalt in Second Copper Precipitate

Addition		Residue			Extract		
H_2SO_4, G	Original Solution	Co, G	Cu, G	Fe, G	Co, G	Cu, G	Fe
0.2	0	0.011	0.394	0.003	0.0139	0.005	Trace
0.4	0	0.0013	0.360	0.003	0.0248	0.034	Trace
0.6	0	0.0004	0.237	0.003	0.0256	0.157	Trace
0.8	0	0.0003	0.085	0.003	0.0256	0.298	Trace
0.0	300 cc	0.0016	0.421	0.004	0.0205		

Table XVIII. Standards of Degree of Oxidation and Reduction

	Co in Slag, Pct	Mn in Crude Co, Pct
1st stage	0.1-0.2	3-5
2nd stage	5-10	0.1-0.05

Table XIX. CoO, MnO Reduction Equilibrium

Alloy		Slag		
Mn, Pct	Co, Pct	Mn, Pct	SiO_2, Pct	CaO, Pct
5.41	0.05	11.80	25.70	38.09
3.77	0.22			
1.14	0.59	31.61	37.86	
1.00	0.50	30.14	38.94	
0.57	0.67	30.79	39.94	
0.26	1.43	32.27	37.22	
0.20	1.67	31.78	35.72	
0.07	6.29	27.52	34.66	

The soda and chlorine additions were so regulated as to maintain a pH of 5.0 to 5.5 and an excess of chlorine, including MnO_4' and ClO', of 0.05 to 0.1 g per liter. The pH was determined with test papers and the free chlorine by simplified permanganometry, both tests being made on the job. Lime cannot be substituted for soda ash in this process since the calcium sulphate thus formed accompanies the cobalt precipitate which in the subsequent reduction process yields cobalt sulphide instead of the desired metallic cobalt. Although the cobalt precipitate obtained was impure the process did serve to produce a concentrate from the dilute leach solution. The analysis of the precipitate was: Co, 30 to 35 pct; Cu, 0.5 to 1.0 pct; Fe, 0.5 to 1.0 pct; Zn, 2 to 8 pct; and Mn, 5 to 8 pct.

Reduction of Cobalt Precipitate

The dried precipitate was mixed with coke breeze and flux and melted in a small electric arc furnace. Crude metallic cobalt containing copper and iron was obtained, the manganese was slagged off, and the zinc was eliminated by vaporization. The crude cobalt containing about 90 pct Co, 2 to 5 pct each of Cu and Fe, 0.5 to 1.5 pct Ni, and traces of Mn and Zn, was refined electrolytically.

In the reduction the chemical similarity of the oxides of cobalt and manganese made it necessary to operate in two stages to eliminate manganese. The first stage was a reducing fusion wherein all of the cobalt and a small amount of the manganese were reduced. The second stage was an oxidizing fusion wherein the manganese was oxidized into the slag by the addition of crude cobalt precipitate. This eliminated the manganese but gave a slag containing cobalt which was recovered by returning the slag to the first stage. The degree of reduction and oxidation in the two stages was adjusted according to the cobalt content of the slag as shown in Table XVIII, based on a study of the equilibrium, Table XIX. The corresponding alloys and slags were obtained by melting CoO, MnO_2, charcoal, and siliceous sand in various proportions in a crucible over an oxygen-coal gas burner.

Electrolysis

The literature on the electrolytic refining of cobalt is scanty and many details remain to be studied. Nevertheless, pure metallic cobalt was commercially produced by the electrolytic process here described.

The crude metallic cobalt from the fusion described above was cast into anode plates. Cobalt sulphate served as electrolyte and pure metallic cobalt was deposited on copper cathodes. Diaphragms must be used to separate anolyte and catholyte to prevent iron, which dissolves from the anode, from depositing on the cathode. Purified electrolyte was fed continually to the cathode chamber from which it passed through the diaphragm into the anode chamber where it picked up iron. It then left the anode chamber for purification and recirculation.

The electrolytic tank was constructed of wood lined with sheet lead. A separate chamber for each cathode was constructed of a wooden framework with sheets of cotton cloth on both sides serving as diaphragms. The anodes were 380x590 mm, and cathodes were 400x600 mm. Ten anodes were placed at a spacing of 160 mm.

Although the cathode deposit was not smooth, a week of continuous electrolysis gave no serious difficulty at a current density of 1 amp per sq decimeter and a bath voltage of 1.5 v at 50°C. Current efficiency was about 90 pct. Anode dissolution presented no particular problem, the only unexpected behavior was that copper in the anode remained undissolved as anode slime. Iron, manganese, and zinc, if any, were dissolved almost 100 pct.

The electrolyte was held to about 30 g Co per liter and the sulphate and ammonium ion concentrations regulated to correspond to a nearly equimolecular mixture of cobalt sulphate and cobalt ammonium sulphate. The pH of the solution was maintained at 5.5 after purification, since lower values made it difficult to eliminate iron and higher values gave a rough cathode deposit. Boric acid additions to the electrolyte improved the deposit but it was not used because of its scarcity. The circulation rate was 200 cc per amp-hr which was sufficient to protect the catholyte purity from infiltration of anolyte iron. This value is four times larger than theoretical, based on a diaphragm area 40 pct greater than the cathode area.

Iron was eliminated from the electrolyte by adding ammonium hydroxide to the air-agitated solution at 70°C. The ammonium sulphate which built up was eliminated as $CoSO_4(NH_4)_2SO_4 6H_2O$. The double salt was roasted at 550° to 600°C to drive off ammonium sulphate. The residual cobalt sulphate was returned to the electrolyte.

Manganese in the anodes will go into solution where it remains, but zinc will deposit, necessitating complete removal of the latter at the anode furnace.

Table XX. Treatment and Production

Period of Operation		Cinder Treated, Ton	Co Produced, Kg
September to December	1943	7,082	0
	1944	24,897	6298
January to August	1945	5,413	1373
	Total	37,392	7671

Plant Construction

The pilot plant was operated during 1941 and the commercial plant design was started in 1942. It was decided that the capacity should be 300 tons of pyrite concentrate per day which was the tonnage expected from the Besshi mine. The most serious

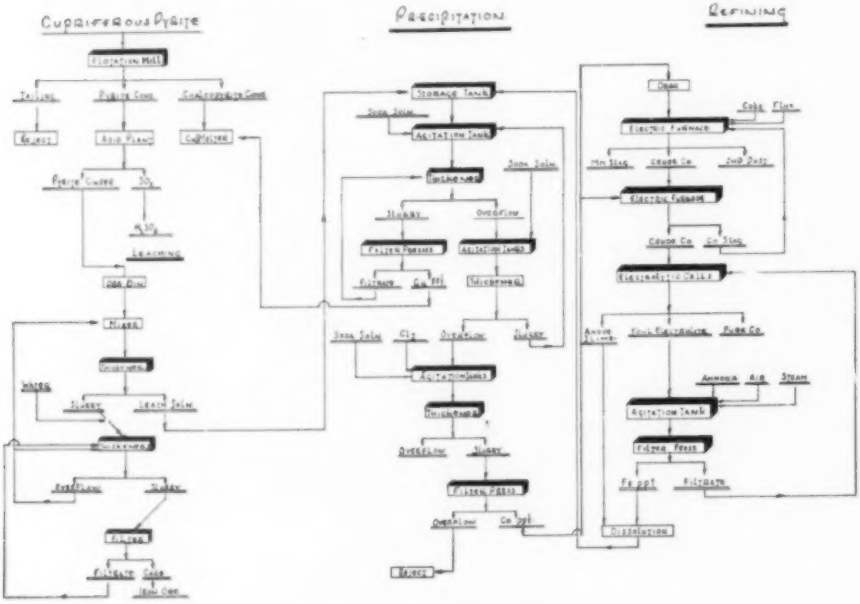

Fig. 1—Flowsheet of cobalt production.

Table XXI. Analyses of Intermediate Products (Average)

Name of Products	Quantity Treated per Month	Unit	Co	Cu	Fe	Zn	Mn	Ni	S
			June 1944						
Pyrite concentrate	3025 ton	Pct	0.10	0.28	40.76	0.37	0.03	Trace	47.53
Pyrite cinder	2180 ton	Pct	0.14	0.41	54.20	0.11	0.04		0.65
Pyrite cinder (soluble part)		Pct	0.055	0.11	0.04	0.04	0.01		
Leach solution	4292 cu m	G/L	0.22	0.69	0.19	0.10	0.02		
Copper precipitate	9370 kg	Pct	0.21	25.19	13.74	2.94	0.35		
2nd copper precipitate		Pct	4.24	17.15	6.55	4.50	0.32		
Cobalt precipitate	2523 kg	Pct	36.42	0.50	0.78	2.99	5.80	0.01	2.13
			October 1944						
Cobalt precipitate	2674 kg	Pct	31.66	1.00	2.40	10.65	5.83		
Anode	1274	Pct	88.40	2.77	4.38	Trace	0.34		
Manganese slag	912	Pct	0.26	0.07	1.88	0.20	6.58		
Cobalt slag	581	Pct	9.26	0.16	5.70	0.28	6.06		
Zinc oxide dust	58	Pct	2.76			53.81			
Pure cobalt	740	Pct	99.35	0.11	0.07	Trace	Trace	0.26	
Iron precipitate	117	Pct	15.36	0.08	22.56	Trace	0.45		
Anode slime	114	Pct	22.66	22.10	5.51	Trace	0.22		
Pure electrolyte		G/L	29.63	Trace	0.005	Trace	0.56		
Foul electrolyte		G/L	29.60	Trace	0.26	Trace	0.53		

problem was the selection of corrosion resistant materials. Acid was not to be used which helped somewhat, however, the corrosive action of copper sulphate and the erosion by the ore slurry was still a difficult combination to overcome. Cupro-nickel or 18-8 stainless steel were best suited, but they were in scarce supply. Consequently tanks, pipes, and air lift pumps were made of reinforced concrete. A few parts including an air nozzle were made of 13 pct Cr steel. Launders and agitator were made of wood, and pumps were of bronze or hard lead. All equipment except the roasting furnace was made on the job. Construction started in August 1942 and was completed in August 1943 at a cost of about 1,000,000 yen. Arrangement of the main equipment is indicated in Fig. 1.

Commercial Operation

The operation was started in September 1943 and continued successfully until the surrender in 1945. The quantities treated and produced and some examples of analyses of raw material, intermediate and final products are shown in Tables XX and XXI.

Economics

The project was demanded by the war economy regardless of cost, but it represents a sincere effort on the part of the author to develop a process which would be profitable even in peace time. Indeed the operating cost under normal conditions estimated from the actual results show a cost less than the prewar price of cobalt. However, the actual cost calculated from the data of the short operating period was high owing to the high repair costs incurred by the small but numerous faults of the equipment in the early days of operation. In fact, the process was profitable even during the war in comparison with other plants in Japan upon whose costs the controlled price of cobalt was based. Further reduction in cost is anticipated by substituting milk of lime for most of the soda ash which is responsible for a large part of the cost, or by replacing chlorine and soda ash for cobalt precipitation with bleach solution produced by direct electrolysis of sea water.

Summary

Metallic cobalt was obtained from cupriferous pyrite as a byproduct of copper production at Besshi mine and smelter, Japan. The project was undertaken because, since the early thirties, it was necessary for Japan to be self-sufficient in cobalt. The research work started in 1939 and was finished in 1940. The pilot plant was operated in 1941 and the final plant produced cobalt from 1943 until the Japanese surrender in 1945. About 7 tons of metallic cobalt were produced from approximately 37,000 tons of pyrite cinder.

Owing to the extremely low grade of the ore (0.1 pct Co) it was difficult to make the project profitable, however this was accomplished by the process which is summarized as follows:

1—Iron pyrite concentrate, obtained as froth from the flotation mill after separating chalcopyrite, was treated for cobalt production. It was roasted for sulphuric acid production and then leached.

2—The leach solution, containing $CuSO_4$, $FeSO_4$, $ZnSO_4$, and $MnSO_4$, in addition to $CoSO_4$, was treated by a simple process to obtain a crude cobalt precipitate after a rough elimination of copper and iron. A complete refining of cobalt was not intended because of the expense of treating large quantities of solution by a complicated procedure.

3—Crude metallic cobalt was obtained from the precipitate by a reducing fusion which eliminated zinc and manganese whose removal would otherwise have been difficult.

4—The crude metallic cobalt was refined by electrolysis.

5—Because of shortages of construction material the whole process was designed to use few units of simple design and special stress was laid on this requirement during development.

Acknowledgment

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Effects of Precompression On The Behavior of the Aluminum Alloy 24ST4 During Cyclic Direct Stressing

by S. I. Liu

THE effects of strain histories, consisting of several prestrains in opposite directions, on the flow and fracturing characteristics of metals determined in a final test have been investigated previously.[1-6] Such strain histories vary from a single prestrain in tension or compression to the number of strain cycles leading to fatigue failure.[1] Between these two limits, various strain histories could be visualized and some can be attained readily. One such example is a strain history consisting of a first prestrain in tension of various magnitudes and a second prestrain in compression also of various magnitudes.[2] In this investigation the strain history was extended to the combination of these two limits, i.e., a single prestrain in tension or compression followed by balanced strain cycles of a selected magnitude $\epsilon_a = \pm 0.12$. It was found in this case that only compressive initial prestrains could be investigated with sufficient accuracy.*

Such strain histories can be considered also as (low cycle) fatigue tests of a metal subjected to various amounts of cold working. It appears from previous publications that cold working within a wide range of reductions usually raises the unnotched fatigue strength of many metals.[4-6] This effect, however, has been found to be inconsistent and sometimes reversed for other metals.[5, 7] Furthermore, Ludwik reports that the yield strength of cold-worked specimens may be reduced by cyclic strains, while that of materials without cold work is generally increased in the initial cycles.[5, 8]

In addition to the above tests, a study was made of the effect of intermediate re-solution heat treatment on low cycle fatigue behavior. Such anneals should eliminate the strain hardening induced by the cyclic strains. As far as their effect on the fracture characteristics is concerned, a few previous tests seemed to indicate that the damage resulting from cyclic strains is retained only partially after heat treatment.[10]

A further investigation was made in which one specimen was subjected to repeated unbalanced tension cycles in which the strain interval was approximately $+0.013$. This repetition of plastic tension damages the material slightly. This result appears to confirm Ludwik's observations.[5, 8]

Fig. 1 (right)—Test specimen for cyclic loading.

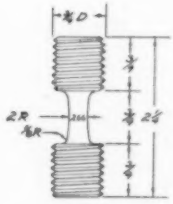
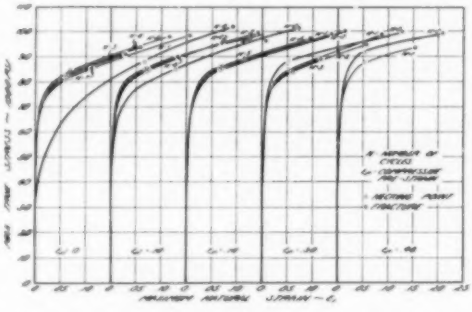


Fig. 2 (below)—Stress-strain curves for the precompressed aluminum alloy 24ST4 after various strain cycles at a strain of $\epsilon_a = \pm 0.12$.



Commercial $\frac{3}{4}$-in. rod of the aluminum alloy 24ST4 was selected for this investigation. The material was subjected to the following treatments before machining: 1—Re-solution treatment at 920° ± 10°F for 45 min, 2—water quench at room temperature, and 3—aging for four days at room temperature.† The treated material then was machined to desired specimen contour and tested. A coolant was used during machining to minimize any artificial aging effects of heating during machining. In some cases the 24ST4 specimens were reheat treated after having been strained. In these cases, the heat treatment was the same as the re-solution heat treatment described above.

Procedure

As shown in Fig. 1, threaded end specimens with a minimum diameter of 0.266 in. and a contour radius of 2 in. were used for prestraining to an axial compressive strain ranging from $\epsilon_p = -0.10$ to $\epsilon_p = -0.48$. For large prestrains, two consecutive com-

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This investigation is one of a series of reports in a research program conducted at the Metals Research Laboratory, Case Institute of Technology, Cleveland, in cooperation with The Office of Naval Research, U. S. Navy.

* After a comparatively large initial tension and machining, necking no longer took place at the original minimum section.

† This alloy reportedly is stable as regards mechanical properties after a natural aging period of four days.

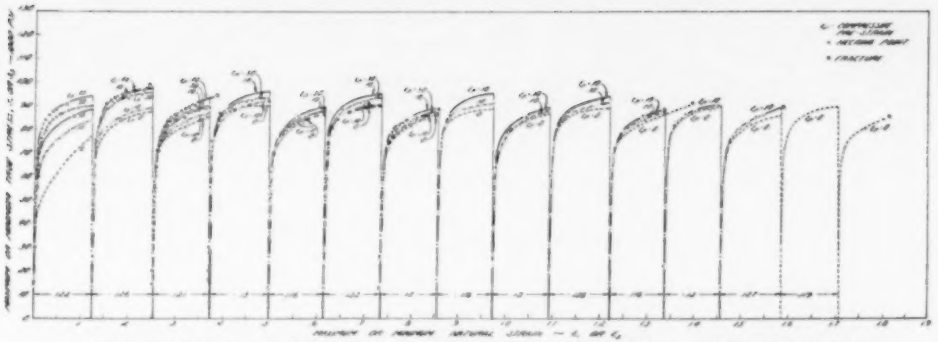


Fig. 3—Cyclic stress-strain characteristics of the aluminum alloy 24ST4 after various amounts of precompression.

pressions with an intermediate machining were applied, the amount of compressive strain performed in each single compression being kept below $\epsilon_p = -0.30$ to avoid buckling. The precompressed specimen was machined to its initial contour and finally subjected to cyclic straining. Each strain cycle consisted of a first strain in tension $\epsilon_1 = +0.12$ and a second strain in compression $\epsilon_2 = -0.12$. Such tension-compression strain cycles were carried on until fracture took place. To investigate the progressive change in fracturing characteristics, specimens were subjected to failure in tension after various numbers of cycles. As was pointed out before, no significant change in specimen contour was observed after each cycle.

The prestrains, the strain cycles, and the final testing all were done on a regular hydraulic 60,000-lb tensile machine. Concentricity during compression was obtained by using a truncated-cone-shaped fixture attached to an antifriction die set and concentricity during tension, by using a specially designed fixture.[11] The change of diameter at the minimum section in either tension or compression was measured by means of a radial strain gage which measured changes in diameter directly to 0.0001 in.[1] The stress-strain relations for all strain cycles and all final tests thus obtained are presented in Figs. 2 to 12.

Symbols

Cyclic strain ϵ_a	=	Either one of two limits of natural strain in a balanced strain cycle consisting of a first strain ϵ_1 in tension and a second strain in compression ϵ_2, ($\epsilon_2 = -\epsilon_1$).
Prestrain ϵ_p	=	Prestrain in either tension (positive) or compression (negative).
Fracture stress S_f	=	Load at fracture divided by the area at the minimum section at the moment of fracture.
Retained ductility ϵ_f	=	Maximum natural strain after fracture.
Number of cycles N	=	Number of repetitions of strain cycles.
Changes in fracture stress $(S_f)_a$	=	Change in fracture stress due to precompression only (n = constant).
$(S_f)_p$	=	Change in fracture stress due to strain cycles only (ϵ_p = constant).
Changes in retained ductility:		
$(\epsilon_f)_a$	=	Change in retained ductility due to precompression only (n = constant).
$(\epsilon_f)_p$	=	Change in retained ductility due to strain cycles only (ϵ_p = constant).

Results

Effects of Precompression on the Flow Characteristics during Cyclic Loading: The changes in flow characteristics are illustrated in Figs. 2 to 5. Each family of curves in Fig. 2 corresponds to a given value of precompression, and each family consists of stress-strain curves obtained on specimens tested after various numbers of strain cycles. In Fig. 3, stress-strain curves for each given value of precompression were plotted in the sequence of straining, regardless of the difference in the signs of stresses and strains. In Fig. 4, each family of curves corresponds to a given number of cycles, and each family consists of stress-strain curves from specimens strained to various values of precompression before the given number of cycles. The stress required to perform the selected value of strain (± 0.12), the true necking stress, and the conventional tensile strength are plotted in Figs. 5a and b, as functions of the number of cycles.

From Figs. 2 to 5, the following can be deduced regarding the effects of precompression on the flow characteristics:

1—Cyclic straining of a re-solution heat treated metal apparently creates two superimposed and counteracting effects; namely, strain hardening and deterioration. For a given magnitude of cyclic strain, strain hardening disappears after a certain number of cycles, while the deteriorating effect continues until a fatigue-type fracture takes place. As shown in Fig. 2, for the selected value of cyclic strain ($\epsilon_a = \pm 0.12$) the net effect of the first cycle could be either strain hardening or deterioration, depending upon the magnitude of the precompression. For small precompressions between 0.00 and -0.18, the effect of the first cycle is strain hardening and the amount of strain hardening decreases with increasing precompression; on the contrary, for large compressions between -0.3 and -0.48, the net effect of the first cycle is deterioration as shown by the lowered stress-strain curves after the first cycle.

2—As shown in Figs. 3 and 4, as the number of

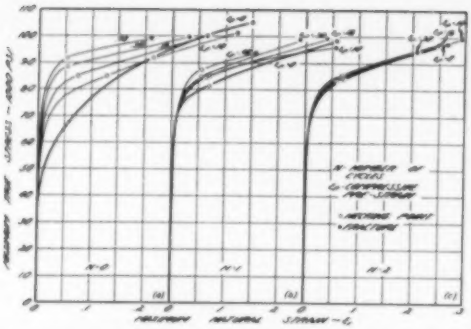


Fig. 4 (left)—Stress-strain curves for the precompressed aluminum alloy 24ST4 after various strain cycles at a strain of $\epsilon_a = \pm 0.12$.

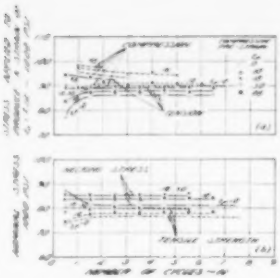


Fig. 5 (right)—Effect of precompression on the flow characteristics of the aluminum alloy 24-ST4 under cyclic straining at a strain of $\epsilon_a = \pm 0.12$.

straining cycles increases, the stress-strain curves for various magnitudes of precompression approach each other. Moreover, a reversal of the order of strain hardening takes place after two cycles, i.e., the stress-strain curves after the first several cycles become lower than those of the first several cycles. These appear to be the results of the counteraction between strain hardening and deterioration.

3—As shown in Fig. 5, the stresses required to perform the desired cyclic strain, the necking stress, and the tensile strength all remain constant after the first cycle. The yield strength after large precompressions decreases slightly with increasing number of cycles.

Effects of Precompression on the Fracturing Characteristics under Cyclic Straining: The total strain history introduced in this investigation consisted of two parts: The precompression and the following strain cycles. In order to visualize the combined effects of both on the fracturing characteristics of the material, the individual effect of each part should be considered. Thus the following four quantities were introduced here for graphical representation of experimental results:

$(\epsilon_f)_n\ (S_f)_n$ = change in ductility and fracture stress due to precompression only (n = constant)

$(\epsilon_f)_p\ (S_f)_p$ = change in ductility and fracture stress due to strain cycles only (ϵ_p = constant)

The changes in fracturing characteristics are shown in Figs. 6 to 9. Fracture stress and the retained ductility were plotted as functions of the number of cycles in Fig. 6 and as functions of the magnitude of prestrain in Fig. 7. In order to visualize the effects of the presence of one part of the strain history on the effects of the other, Figs. 8 and 9 were constructed as follows: The curves in Fig. 6 were shifted to a common origin; by so doing, the stress coordinate became the quantity $(S_f)_p$ and the ductility coordinate became the quantity $(\epsilon_f)_p$ as shown in Fig. 8. By the same procedure, Fig. 9 was deduced from Fig. 7. From these figures, the following could be deduced regarding the effects of such strain history (precompression followed by strain cycles) on the fracturing characteristics:

1—The effects of precompression on the fracture stress after varying number of strain cycles were:

(a) The fracture stress of the virgin material was decreased with increasing compression, as shown in Figs. 6a and 7a.

(b) The rate of reduction in fracture stress by cyclic straining was increased by precompression as shown in Fig. 8a.

2—The effects of strain cycles inserted between the precompression and the final testing on fracture stress for varying precompression were as follows:

(a) The fracture stress of the virgin material was decreased with increasing number of strain cycles as Figs. 6a and 7a.

(b) The rate of reduction in fracture stress by

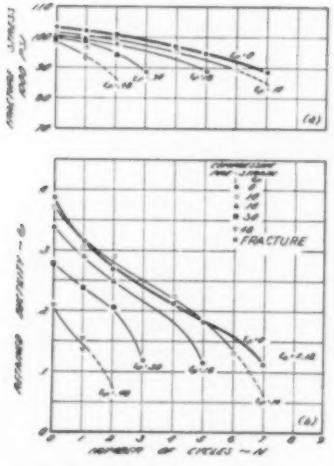
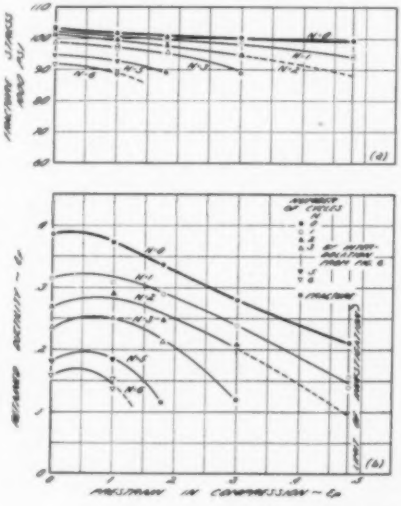


Fig. 6 (left)—Effect of strain cycles ($\epsilon_a = \pm 0.12$) on the fracturing characteristics of the aluminum alloy 24ST4 after various amounts of compressive prestrain.

Fig. 7 (right)—Effect of precompression on the fracturing characteristics of the aluminum alloy 24ST4 under cyclic straining at a strain of $\epsilon_a = \pm 0.12$.



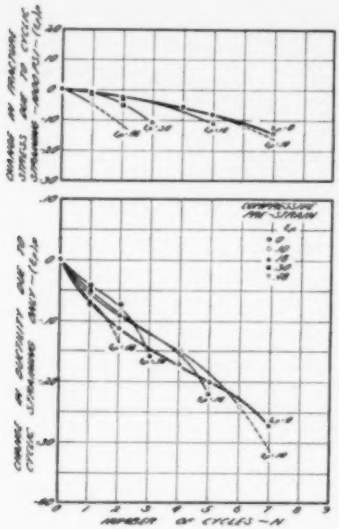


Fig. 8 (left)—Change in fracturing characteristics of precompressed aluminum alloy 24ST4 due to cyclic straining ($\epsilon_a = \pm 0.12$) as functions of the number of cycles.

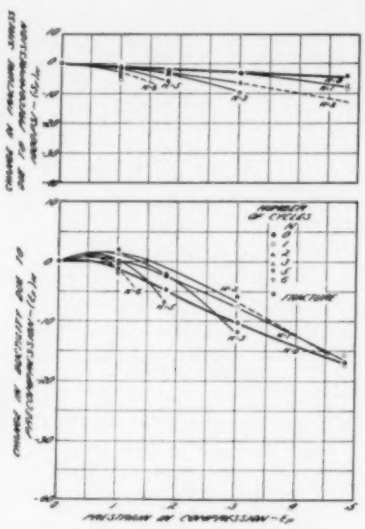


Fig. 9 (right)—Change in fracture characteristics of the cyclically strained aluminum alloy 24ST4 ($\epsilon_a = \pm 0.12$) due to precompression as functions of the precompression.

precompression was increased by inserted strain cycles as shown in Fig. 9a.

Thus it appears that within the range of precompression and number of cycles investigated, each of these two factors, precompression and cyclic straining, causes a reduction in fracture stress of the material when acting alone; on the other hand, when acting together, the combined effect appears greater than the sum of the two individual effects.

3—The effects of precompression on the retained ductility after varying numbers of strain cycles were as follows:

(a) For precompressions at magnitudes greater than 0.10, the ductility of the virgin material was decreased with increasing precompression as shown in Fig. 6b and 7b.

(b) As shown in Fig. 6b, and the previous investigation,[1] the ductility of the material was decreased suddenly between the last cycle and the fatigue fracture. Fig. 8b shows that precompression increases the rate of such reduction in ductility and accelerates the approach of such a sudden reduction, i.e., accelerates the occurrence of fracture. However, the test data also show that except in the last cycle, the rate of reduction in ductility by cyclic straining was decreased by precompression.

4—The effects of strain cycles inserted between precompression and the final testing on the retained ductility for varying precompression were:

(a) The ductility of the virgin material was decreased with the increasing number of strain cycles as shown in Fig. 6b and 7b.

(b) The rate of change in ductility due to precompression was changed with the increasing number of inserted strain cycles. As shown in Fig. 9b for precompressions of magnitude greater than 0.10, the rate of reduction in ductility by precompression increases with increasing number of cycles.

Previous investigations showed that cold working in drawing or rolling up to very high reduction usually increased the unnotched strength of metals.[4-6] This investigation, however, indicates that the effect of precompression is opposite to the effect of drawing or rolling. It previously was found in this laboratory and also by other authors, that prestrain in drawing or rolling increases, while prestrain in compression decreases, the fracture stress of many metals in the subsequent tensile test.[5] This finding appears to be in good agreement with the results of this investigation.

Effects of Intermediate Reheat Treatment‡ on Low Cycle Fatigue Behavior: Fig. 10 shows the stress-strain curves in tension up to fracture after different numbers of cycles, for specimens without intermediate re-solution heat treatment, specimens with intermediate re-solution heat treatment after each cycle, and specimens with only one re-solution heat treatment before the final testing. In this case, no precompression was used. The figure shows that even after re-solution heat treatment, the stress-

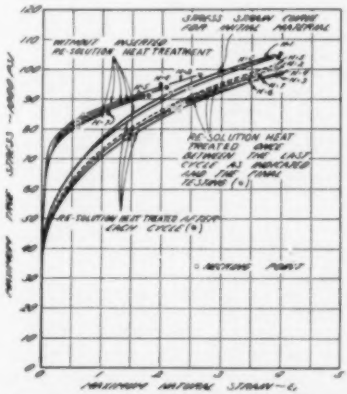


Fig. 10—Stress-strain curves for the aluminum alloy 24ST4 after cyclic straining at a strain of $\epsilon_a = \pm 0.12$ with and without inserted re-solution heat treatment, showing the permanent damage done by cyclic straining.

‡ In this series, the reheat treatment consisted of the regular solution heat treatment and natural aging described earlier in this paper.

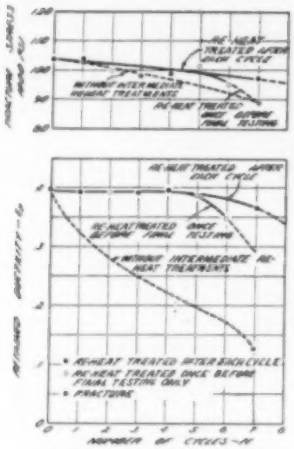


Fig. 11 (left)—Fracturing characteristics of the aluminum alloy 24ST4 under cyclic straining at a strain of $\epsilon_0 = \pm 0.12$ with and without intermediate reheat treatment, showing the permanent damage done by cyclic loading.

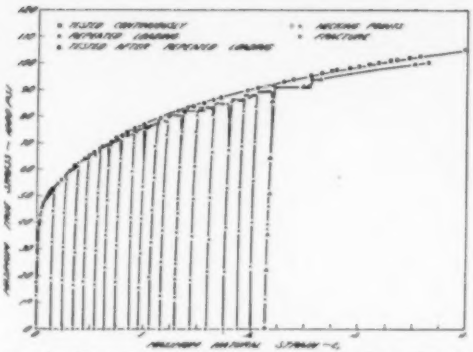


Fig. 12 (right)—Effect of repeated plastic tension on flow and fracture characteristics of the aluminum alloy 24ST4.

strain curves of the cyclically strained material are lower than the stress-strain curve of the virgin material.

In Fig. 11, the fracturing characteristics for specimens with and without inserted reheat treatment were plotted as functions of the number of cycles. This figure reveals that after a certain definite number of cycles, five in this case, the ductility of the cyclically strained material can no longer be restored to the value of the virgin material, regardless of the number of intermediate reheat treatments. However, at higher number of cycles, the amount restored by successive reheat treatment after each cycle is larger than that restored by a single reheat treatment before the final testing.

These all point to one fact, that the metal was damaged permanently by cyclic straining. This appeared to confirm the previous findings.[10]

Stress-strain Curves for 24ST4 in Repeated Tension: Fig. 12 shows the stress-strain curves for two specimens of the same material, one tested in tension continuously and the other subjected to 19 strain repetitions at a strain interval of approximately 0.01 and tested to fracture. Such repetitions of small plastic strains caused the following changes in the stress-strain behavior of this material: 1—Both the flow and the fracturing characteristics were slightly lowered. 2—A pronounced yield jog which the virgin material does not possess appeared after a number of repetitions.

Such slight reduction in both flow and fracturing characteristics is due apparently to the damages done by repeated loading.

Conclusions

The experimental results lead to the following conclusions regarding this investigation:

1—Cyclic straining of re-solution heat treated 24ST4 creates two superimposed and counteracting effects, namely, strain hardening and deterioration. After small amounts of precompression, strain hardening prevails during the first few cycles, while after large precompression, deterioration prevails from the first cycle, Fig. 2.

2—When acting alone, either of the two factors, precompression or cyclic straining, causes a reduction in fracture stress of this material; on the other hand, when acting together, the combined effect is greater than the sum of two individual effects, Fig. 8.

3—Within the range of precompression and the number of cycles investigated, precompression accelerates the approach of fracture, Fig. 6.

4—Cyclic straining permanently damages the material, Figs. 10 and 11.

5—A pronounced yield jog appears after repeated tension cycles, and the flow and fracturing characteristics are slightly lowered, Fig. 12. This yield jog is not present in the virgin unstrained metal.

Acknowledgments

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Effect of Alloying Elements on The Electrical Resistivity of Aluminum Alloys

by A. T. Robinson and J. E. Dorn

The electrical resistivities of aluminum alloys containing Cu, Ge, Zn, Ag, Cd, and Mg were found to increase linearly with the atomic percentage of the solute atoms. Application of Linde's rule to these data suggests that each aluminum atom contributes 2.5 electrons to the metallic bond.

ALTHOUGH aluminum invariably exhibits a valence of three in ionic solids, it does not follow necessarily that its valence in the metallic state is also three. As a matter of record, many properties suggest that the number of bonding electrons in metallic aluminum is less than three. For example, as shown in Fig. 1, the atomic radii[1] of the metallic elements in the solid state decrease with increasing atomic number at the beginning of any one period. The atomic radius of aluminum, however, is greater than that which would result from a regular decrease in atomic radius with increasing atomic number, suggesting that the number of bonding electrons in aluminum is somewhat less than three.

Correlated with the anomalously large atomic radius of aluminum is its abnormally low melting temperature. As the atomic numbers increase in any one period, the melting temperatures of the metallic elements increase.[2] As shown in Fig. 2, however, the melting temperature of aluminum (13) is only slightly greater than that of magnesium (12). Again the number of bonding electrons in metallic aluminum appears to be nearer two than the expected value of three.

In addition Ageev and Ageeva[3] calculated the electron density distribution in the aluminum lattice. A comparison of such electron density curves for various assumed valence states of aluminum with experimentally determined curves suggests that the actual number of bonding electrons in metallic aluminum is between two and three. Hume-Rothery and Raynor[4, 5] have suggested that the above-mentioned abnormalities are associated with the overlapping of the Brillouin zones of metallic aluminum when it is in the usual face-centered cubic structure.

The importance of the number of bonding electrons in metals has been extended recently into the field of mechanical properties. While formerly it was thought that the plastic properties of alpha solid solutions were primarily dependent upon the lattice strain induced in the solvent by the solute, it is now known that the difference in the number of bonding electrons of the solute and solvent also has its influence on the plastic properties.[6, 7] In order to achieve a satisfactory correlation of the effect of alloying elements on the plastic properties of aluminum alloys,[6, 7] however, it was necessary to assume that the number of bonding electrons contributed by aluminum was about two rather than the expected value of three. It appeared to be desirable, therefore, to seek other criteria for evaluating the number of bonding electrons contributed by aluminum to its alpha solid solutions, especially in view of the practical as well as the theoretical importance of the effect of valency on the plastic properties.

Norbury[8] was perhaps the first to illustrate that the increase in resistance of alpha solid solutions is associated with the differences in valence of the solute and solvent metals. In a series of illuminating investigations Linde[9–11] has shown that the electrical

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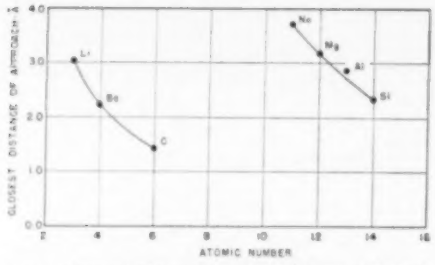


Fig. 1 (above)—Variation of interatomic distances with atomic number. Data from Metals Handbook.

Fig. 2 (below)—Variation of melting temperatures with atomic number. Data from Metals Handbook.

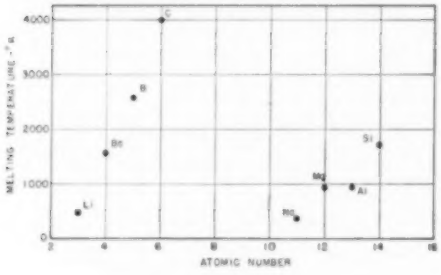


Table I. Equation Constants Used for the Calculated Change in Resistance of Copper, Silver, and Gold Alloys

Element	Atomic Number	Z_β	k_1	k_2
Copper				
Cu	29	$(1)_\alpha$		
Zn	30	2	0.4175	0
Ga	31	3	0.4175	0
Ge	32	4	0.4175	0
As	33	5	0.4175	0
Ag	47	1	0.322	0.1172
Cd	48	2	0.322	0.1172
In	49	3	0.322	0.1172
Sn	50	4	0.322	0.1172
Sb	51	5	0.322	0.1172
Au	79	1	0.478	0.522
Hg	80	2	0.478	0.522
Silver				
Cu	29	1	0.536	0.0683
Zn	30	2	0.536	0.0683
Ga	31	3	0.536	0.0683
Ge	32	4	0.536	0.0683
As	33	5	0.536	0.0683
Ag	47	$(1)_\alpha$		
Cd	48	2	0.456	0
In	49	3	0.456	0
Sn	50	4	0.456	0
Sb	51	5	0.456	0
Au	79	1	0.437	0.358
Hg	80	2	0.437	0.358
Tl	81	3	0.437	0.358
Pb	82	4	0.437	0.358
Bi	83	5	0.437	0.358
Gold				
Cu	29	1	0.488	0.4403
Zn	30	2	0.488	0.4403
Ga	31	3	0.488	0.4403
Ge	32	4	0.488	0.4403
Ag	47	1	0.3214	0.314
Cd	48	2	0.3214	0.314
In	49	3	0.3214	0.314
Sn	50	4	0.3214	0.314
Au	79	$(1)_\alpha$		
Hg	80	2	0.3914	0

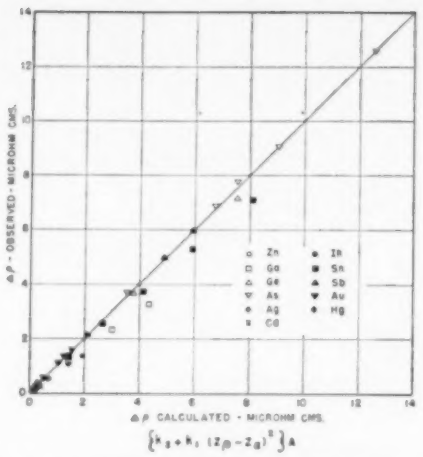


Fig. 3—Agreement between calculated and observed resistance of various solid solution alloys of copper.

resistivity of alpha solid solutions in copper, silver, and gold closely obey the empirical relationship:

$$\Delta\rho = \{k_2 + k_1 (Z_\beta - Z_\alpha)^2\}A \qquad [1]$$

where A is the atomic pct of the solute, Z_α is the valence of the solvent, Z_β is the valence of the solute, $\Delta\rho$ is the increase in resistivity per addition of A, and k_1 and k_2 are constants for any one period from which the solutes are selected.

The validity of the above relationship for alloys of copper is illustrated in Fig. 3 where the observed $\Delta\rho$ is plotted as a function of the calculated $\Delta\rho$ using the values of k_1 and k_2 given in Table I. In Figs. 4 and 5 are shown the validity of eq 1 for silver and for gold alloys using the data of Table I. The good agreement between $\Delta\rho$ observed and $\Delta\rho$ calculated reveals that eq 1 is quite accurate for the alloy systems which have been investigated.

It has been shown by Mott[15, 16] that the results of Linde as expressed by eq 1 have, in part, a simple theoretical explanation: The core of the solvent atom has a charge of $Z_\alpha e$ whereas the core of the dissolved atom carries a charge of $Z_\beta e$ which differs by $(Z_\beta - Z_\alpha)e$ from that of the solvent. But since the intensity of the scattering of the conduction electrons is proportional to the square of the scattering charge, the change in resistivity should be proportional to $(Z_\beta - Z_\alpha)^2$ when other factors are neglected.

In view of the above evidence, it should be possible, by application of eq 1 to alpha solid solutions of aluminum, to deduce the value of Z_α, namely the charge on the core of the aluminum ions in metallic aluminum.

Materials for Investigation

The alloys examined in this investigation were the same as those previously used for the determination of the effect of alloying elements on the plastic properties of aluminum.[5, 7] Their chemical analyses and their lattice constants are recorded in Table II. Each alloy was homogenized, cold rolled, and re-

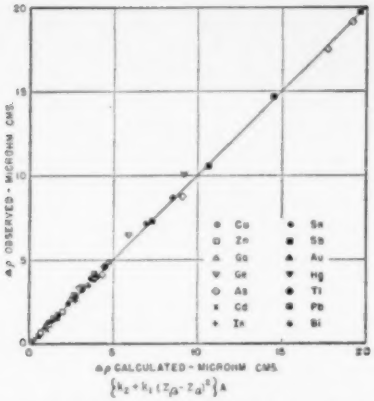


Fig. 4 (above)—Agreement between calculated and observed resistance of various solid solution alloys of silver.

Fig. 5 (below)—Agreement between calculated and observed resistance of various solid solution alloys of gold.

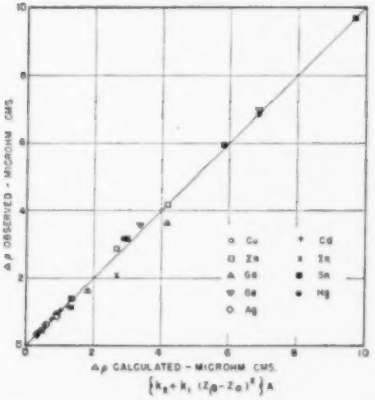
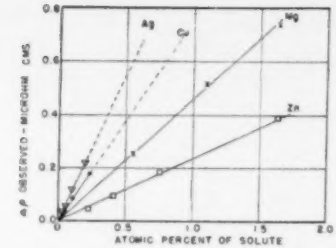


Table II. Chemical Analyses and Lattice Constants

Alloying Element	Atomic Pct	kx Units 25°C Lattice Constant	Atomic No.	Residual Impurities, Wt Pct Si	Fe	Cu	Mg	Mn
Mg	0.554	4.0432(6)	12	0.003	0.003	0.007		
	1.097	4.0454(5)		0.004	0.004	0.007		
	1.617	4.0474(9)		0.003	0.004	0.006		
Cu	0.029	4.0411(0)	29	0.003	0.004		0.0006	0.001
	0.054	4.0408(7)		0.003	0.004		0.0007	0.001
	0.101	4.0406(9)		0.003	0.003		0.0006	0.001
	0.233	4.0403(8)		0.003	0.004		0.0006	0.001
Zn	0.211	4.0411(3)	30	0.004	0.004	0.006	0.001	
	0.402	4.0409(8)		0.004	0.005	0.006	0.001	
	0.755	4.0407(1)		0.004	0.003	0.006	0.001	
	1.616	4.0402(0)		0.003	0.005	0.007	0.001	
Ge	0.015	4.0413(0)	32	0.004	0.004	0.006	0.001	
	0.033	4.0413(5)		0.004	0.004	0.006	0.001	
	0.082	4.0413(9)		0.003	0.005	0.007	0.001	
	0.145	4.0414(9)		0.003	0.006	0.007	0.001	
Ag	0.025	4.0412(8)	47	0.003	0.005	0.006	0.001	
	0.053	4.0412(9)		0.003	0.005	0.006	0.001	
	0.100	4.0413(1)		0.003	0.005	0.007	0.001	
	0.194	4.0413(1)		0.003	0.006	0.007	0.001	
Cd	0.012	4.0411(6)	48	0.004	0.005	0.006	0.001	
	0.029	4.0411(0)		0.004	0.005	0.006	0.001	
	0.043	4.0410(6)		0.004	0.005	0.006	0.001	
	0.085	4.0410(6)		0.004	0.005	0.006	0.001	



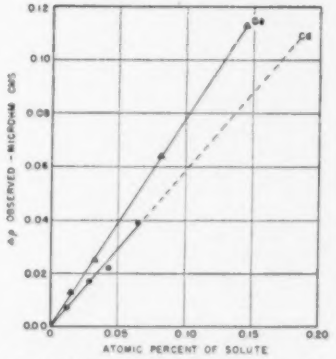


Fig. 6—Effect of alloying elements on the resistance of aluminum.

crystallized to approximately uniform grain size preliminary to the determination of the resistivity.

Experimental Procedure

Sheet-type specimens having nominal dimensions of 0.070 in. thick and 0.250 in. wide were used in this investigation. Their resistance was determined by means of a precision Kelvin double bridge ohmmeter, the specimen length between the potential leads of the Kelvin bridge being fixed at 2.750 in. The width and thickness of the specimens were measured at three points along their length by means of a vernier micrometer with a least count of 0.0001 in. The errors in the resistivity resulting from errors in gaging the specimen were determined

Table III. Effect of Alloying Elements on the Electrical Resistance of Aluminum, Measured Values

Alloy	Atomic Pct	ρ Avg Microhm Cm	Δρ Microhm Cm
Mg	0.554	3.030	0.250
	1.097	3.296	0.516
	1.617	3.520	0.740
Cu	0.029	2.732	0.031
	0.054	2.747	0.036
	0.101	2.783	0.082
	0.233	2.869	0.178
Zn	0.211	2.764	0.044
	0.402	2.811	0.091
	0.755	2.902	0.182
	1.616	3.110	0.390
Ge	0.015	2.760	0.013
	0.033	2.772	0.025
	0.082	2.811	0.064
	0.145	2.860	0.113
Ag	0.025	2.755	0.033
	0.053	2.775	0.053
	0.100	2.838	0.116
	0.194	2.939	0.217
Cd	0.012	2.745	0.007
	0.029	2.755	0.017
	0.043	2.760	0.022
	0.085	2.777	0.039

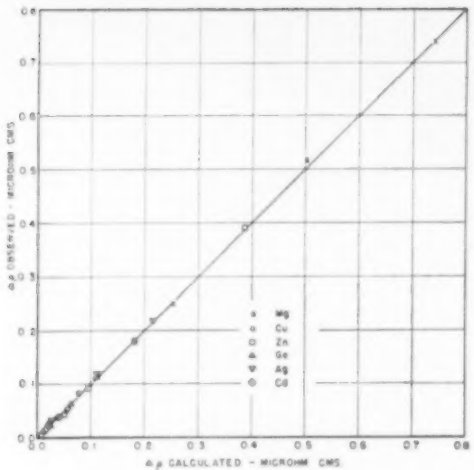


Fig. 7—Agreement between calculated and observed resistance of various solid solution alloys of aluminum.

to be insignificant. The sensitivity of the Kelvin bridge in the range which was used was slightly better than ±0.5 pct. Total errors from these sources may have amounted to about ±0.5 pct (or ±0.015 microhm cm) of the calculated resistivity.

All resistance measurements were made at atmospheric temperature (22° to 26°C) and were corrected to 24°C. Since the temperature coefficient of resistivity of dilute alloys is known to be practically independent of composition,[11] a correction of 0.00429 microhm cm per °C appropriate for 99.996 pct Al[12] was applied to each of the alloys.

Experimental Results

The resistivities of the various alloys as a function of atomic percentage of the alloying element are given in Table III and plotted in Fig. 6. The usual linear increase of the resistivity of dilute solutions with atomic percentage of alloying element was obtained. The value for the electrical resistivity for pure aluminum was obtained by extrapolation of the data for each alloy series to zero concentration.

Discussion and Conclusions

The atomic number and Z_β of each of the alloying elements used in this investigation are given in Table IV. Since elements Cu (29), Zn (30), and Ge (32) are in the same period of the periodic table, Norbury's rule as given by eq 1 was applied to the data obtained from these elements to determine k_1, k_2, and Z_α. The value of Z_α thus obtained was 2.50 and indicates again that the aluminum ion in the metallic state has a charge of about —2.5 electrons.

Table IV. Equation Constants Used for the Calculated Change in Resistance of the Aluminum Alloys

Element	Atomic No.	Z_β	k_1	k_2
Mg	12	2	1.832	0
Al	13	(2.5)		
Cu	29	1		
Zn	30	2	0.2675	0.1731
Ge	32	4		
Ag	47	1		
Cd	48	2	0.2535	0.5446

Using the values of k_1 and k_2 given in Table IV and assuming that the ionic charge of aluminum is —2.50 electrons, the correlation between $\Delta\rho$ calculated and $\Delta\rho$ observed shown in Fig. 7 was obtained.

Thus, the effect of alloying additions of Cu, Zn, Ge, Ag, Cd, and Mg to aluminum on its electrical resistivity has been determined; and applying the Norbury rule to the resistivity of aluminum alloys suggests that the apparent valence of aluminum is approximately 2.5.

Acknowledgments

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[15] P. 810 of ref. 2.

Growth of Molybdenum Single Crystals

by N. K. Chen, R. Maddin, and R. B. Pond

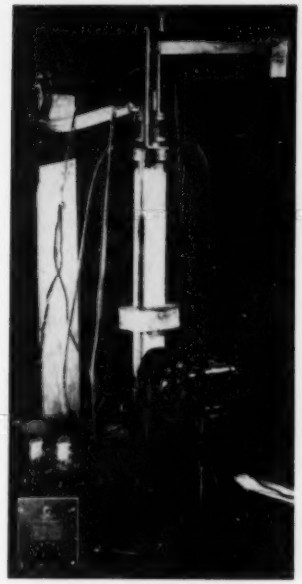

Fig. 1—Modified Andrade furnace.

A METHOD has been described by Andrade[1] for obtaining very rapid grain growth so that single crystals of high melting point metals could be made with comparative ease. The furnace construction was essentially a very thin wire through which was passed an electrical current so that "a high uniform temperature" was maintained. The wire was surrounded by a fused quartz tube from which the air had been evacuated. Andrade applied this method to the growth of single-crystal wires of alpha iron, and Tsien and Chow[2] prepared single crystals of molybdenum 0.25 mm diam in this way.

In the present report a method is described in which the basic idea of the Andrade furnace is utilized. However, modifications are employed so that large single crystals of molybdenum or of any refractory metals can be grown.

Furnace

The modified Andrade furnace is shown in Fig. 1, and the detailed drawing of its construction can be seen in Fig. 2. The furnace proper consists of a $2\frac{1}{2}$-in. diam fused silica tube, 20 in. long, which is evacuated continuously at the bottom. Two water-cooled copper electrodes hold the specimen by means of collets held in place in the electrodes by set screws. These electrodes serve also to transmit power to the specimen. The lower electrodes can be clamped to the stand, while the upper electrode is fastened in place to the bellows which in turn is further connected to one side of the lever arm, flexibly supported at the top. After the specimen is mounted and the vacuum is secured, the lever arm is adjusted by means of the counter weight so

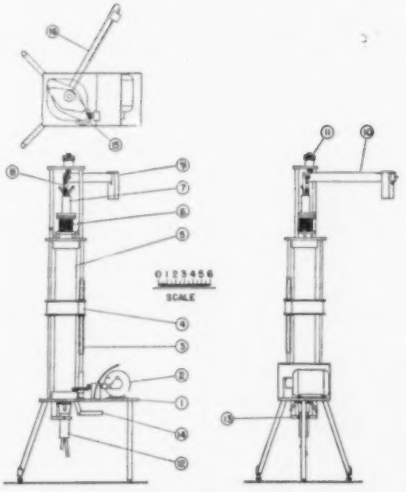

Fig. 2—Details of modified Andrade furnace.

1—Motor and tube support
2—Electric motor for raising subsidiary furnace
3—Jack screw
4—Subsidiary furnace (nichrome)
5—Fused silica tube
6—Bellows
7—Upper electrode
8—Flexible link
9—Beam weight
10—Beam
11—Adjusting screw
12—Lower electrode
13—Lower electrode lock
14—Gas outlet
15—Reduction gears
16—Indicating needle

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that the bellows is at its relaxed position. This insures that the total weight of the specimen, the upper electrode, and the downpull of the vacuum are balanced by the horizontal beam. Any expansion of the specimen on heating should proceed freely, if other frictional forces could be neglected. During the time of heating the specimen, the beam is maintained in a horizontal position by turning the nut at the top, the rotation of the electrode is prevented by a key fitted into a groove. This arrangement proved very desirable in that buckling of the specimen during the high temperature treatment was avoided.

The power is supplied by a motor generator set with a capacity of 550 amp at a maximum of 24 v. Results indicated that for a $\frac{1}{8}$-in. diam, 6-in. long molybdenum rod, a current in the vicinity of 210 amp at 2.5 v could heat the specimen up to an average temperature of 2000°C.

The subsidiary external furnace is wound with nichrome so that the electric heating zone is a cylindrical band $\frac{1}{2}$ in. wide. It can be raised or lowered by the attached motor whose speed may be varied by means of an electronic controller from 0.5 to 15 in. per hr.

Temperature Measurement

The average temperature of the specimen can be measured from the change in its resistance with temperature. As may be seen in Fig. 3, a linear relationship of specific resistance of molybdenum with temperature exists up to its melting point.[7] Thus, when the total current is measured, together with the voltage drop across the specimen, the corresponding resistance can be used to indicate the average temperature. Fig. 4 shows the E-I characteristic curve, measured for three specimens of $\frac{1}{8}$-in. Fansteel molybdenum rod, 6 in. long. The current through the specimen is adjusted by controlling the field resistance of the generator with electric stoves and a rheostat. After the current and voltage have been stabilized corresponding to a particular average temperature of the specimen, this equilibrium condition can be maintained for a long time.

Experimental Results

The original material used was $\frac{1}{8}$ and $\frac{1}{4}$-in. diam, 6-in. long Fansteel molybdenum with a grain size far smaller than could be denoted by any ASTM designation, as shown in Fig. 5. Its longitudinal section exhibited long fibrous grains, Fig. 6. The first specimen, M-1, was heated to an average temperature of about 2000°C for 90 min. Since no arrangement was designed to account for the expansion of the specimen in this first run, the specimen buckled and broke into three pieces, with a brittle fracture, when disassembled from the furnace. Nevertheless, back-reflection Laue photograms exhibited a large amount of grain growth in this short period of heat treatment, as shown in Fig. 7. Three other specimens, M-2, M-3, and M-4, were heated in the furnace according to the time-temperature curve shown in Fig. 8. These attempts still resulted in buckling of the specimens which was probably due to the force necessary to overcome friction in the system, namely, friction of the electrodes against the surface of their receptacles. This was overcome by minimizing the friction.

From Fig. 7 it may be concluded that all three specimens resulted in single crystals of certain lengths. M-3 revealed three grains thermally etched, each extending through the whole crystal with lengths of $\frac{3}{4}$ to $1\frac{1}{4}$ in. The surface of the specimen was bright, the grain boundaries being clearly revealed when the specimen was removed from the furnace. All specimens were electrolytically polished using an electrolyte of 300 cc methyl alcohol, 60 cc H_2SO_4, 130 cc HCl, and a current density of 4 amp per sq in. After etching with $NaOH$-$KFe_3(CN)_6$ solution, the grain boundaries of the large grains, as well as some surface grains distributed as islands in the large grains, could be observed. Thus M-2 showed a grain about 2/5 in. in length which confirmed the X-ray observations shown in Fig. 7, although the lower middle photograms, M-2, exhibited three grains and M-4 two large grains about $1\frac{1}{4}$ in. long extending through the whole specimen. The polycrystalline material shown adjacent to the large single grain in Fig. 9 had an average ASTM grain size of No. 3. With the $\frac{1}{4}$-in. material it was found necessary to recrystallize the as-received molybdenum rod and to extend the specimen 1 to 2 pct in order to provide a strain. Following this procedure, a total of 7 hr was required to produce single crystals approximately $1\frac{1}{2}$ in. long.

While the specimen was maintained at high temperature, considerable evaporation occurred and a film of metal formed on the inside wall of the silica tube. The zone of this deposition extended through the middle 6 in. of the tube.

Discussion

The modified Andrade equipment has overcome the limitations of the original Andrade method in

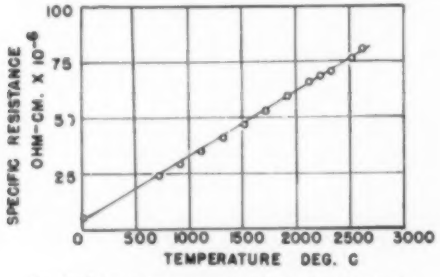

Fig. 3—Effect of temperature on electrical resistance of molybdenum.

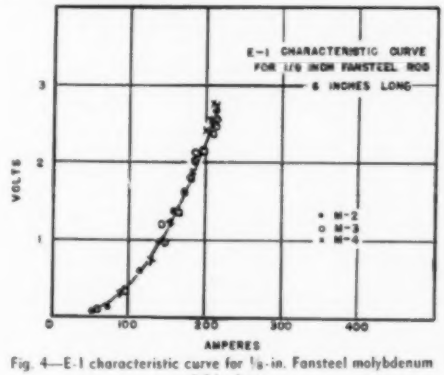

Fig. 4—E-I characteristic curve for $\frac{1}{8}$-in. Fansteel molybdenum rod 6 in. long.

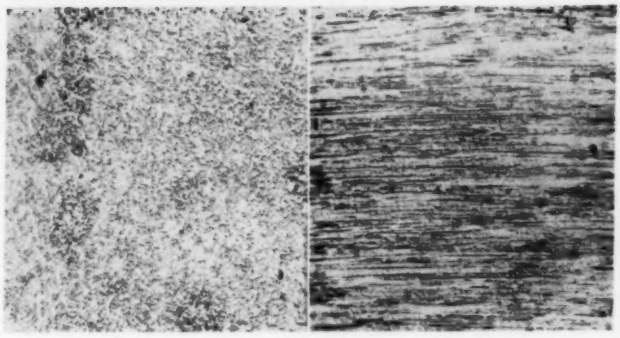

Fig. 5 (left)—Grain size of as-received Fansteel molybdenum ⅛-in. rod cross-section. Etchant NaOH:$K_3Fe(CN)_6$. X100.

Fig. 6 (right)—Grain size of as-received Fansteel molybdenum ⅛-in. rod longitudinal section. Etchant NaOH:$K_3Fe(CN)_6$. X100.

that only very fine wire could be used with his equipment as a starting material. With the present arrangement, material of rather large size, i.e., ½-in. rod, can be converted into single crystalline form.

The very rapid grain growth observed in these experiments over the relatively short time employed is of great interest. Since both ends of the specimen are at room temperature, about 35°C, where the center section is maintained at a temperature higher than 2000°C, a very sharp temperature gradient exists in the specimen. It is not known whether the sharp gradient or the high temperature is responsible for the rapid grain growth, nor is it possible at the present time and with the present equipment to measure or calculate accurately the temperature gradient along the rod. A simple uniform variation of temperature was assumed and the average temperature resulting from this distribution was calculated. With this assumed temperature gradient the total average resistance assuming different lengths of rod was determined. By this method the temperature of the rod was calculated as shown in Fig. 8. There was little doubt that the temperature at the center of the rod exceeded 2000°C when the average temperature for a length of 4 in. was measured as 2000°C.

It is interesting to note that Tsien and Chow, in their original experiments, used the subsidiary furnace "to establish a temperature gradient." Without the use of the subsidiary furnace, single crystals never exceeded 2 mm in length. However, it is probable that the external furnace has little or no effect on the final outcome of the experiments since the sharpest temperature gradient exists in the specimen itself as a result of the water-cooled ends.

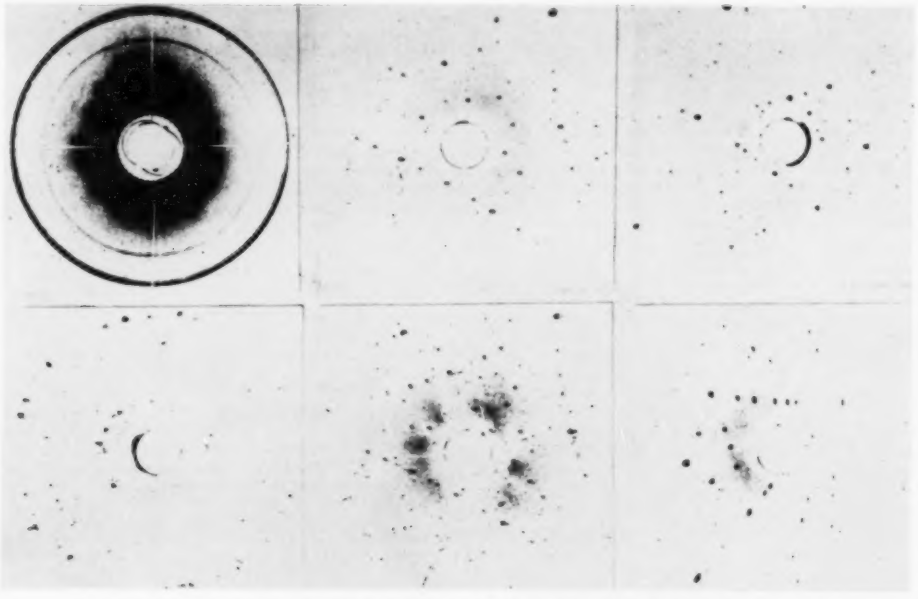

Fig. 7—Back-reflection Laue photographs. Specimens M-2, M-3, and M-4 were treated as shown in Fig. 8. Original material, upper left. Specimen M-1, 40 min at 2000°C, lower left. Specimen M-2, upper center. Specimen M-2, lower center. Specimen M-3, upper right. Specimen M-4, lower right.

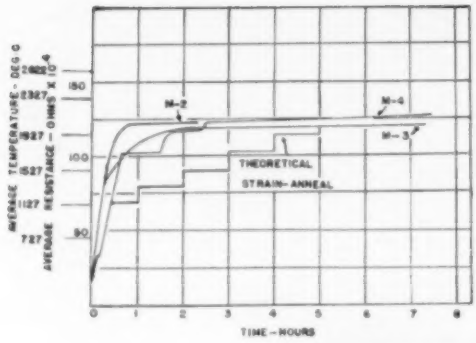

Fig. 8 (left)—Time-temperature curve showing heating process of specimens M-2, M-3, and M-4.

Fig. 9 (right)—Interface between single crystal and fine grained molybdenum rod. Electrolytically polished.

Etchant, NaOH:$K_3Fe(CN)_6$. X150.

No observable difference in the results could be noted when the external furnace was used in the present case.

Acknowledgments

This research was sponsored by the Office of Naval Research under Contract No. ONR 031-339. The authors are indebted to I. R. Kramer, Office of Naval Research, for helpful discussions of this paper. The assistance of W. R. Asher, instrument maker, for helpful suggestions in the manufacture of the furnace and L. G. Richards for metallographic work is gratefully acknowledged.

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Corrections

In the February 1951 issue: *Observations on Rimming Steel Ingots* by A. Hultgren, G. Phragmen, S. Wohlfahrt and J. E. Ostberg. P. 103, in the footnote γ transformation should read δ to γ transformation. P. 105, the last sentence of the ninth paragraph, col. 1, should read: "In the middle portion along the axis, a set of fine pores is seen." In the next paragraph, the next to the last sentence should read: "For this reason the final stage of freezing was associated with a small amount of shrinkage and, in consequence, only small pores and few blowholes were formed." P. 110, in the last sentence H. Gillo should read H. Gille.

In the February 1951 issue: TP 3002E. *Effect of Ternary Additions on the Age-Hardening of a Copper-Silver Alloy* by Harold Margolin and Walter R. Hibbard, Jr. P. 176, Table II, under the heading "3rd Element, Wt Pct" the value for Cu-Ag-Zn should be 0.975 and not 0.075.

In the December 1949 issue: *The Properties of Sand Cast Magnesium-Rare Earth Alloys* by Thomas E. Leontis. P. 974, in Table VII, the tabulated creep limits for 300°F are actually the values for 400°F, which are the same as those plotted in Figs. 18, 19, and 20. The values intended for Table VII under 300°F are as follows:

Table VII. Creep Limits at 500°F

Alloy No.	Composition, Pct	Creep Limit, 1000 psi		
		0.1 Pct Creep Extension	0.2 Pct Total Extension	0.5 Pct Total Extension
		300°F		
2	0.40 Mischmetal	7.8	6.2	8.0
3	1.15 Mischmetal	7.9	6.1	7.2
5	1.62 Mischmetal	8.5	6.4	8.3
6	2.50 Mischmetal	9.7	7.3	9.2
7	2.85 Mischmetal	12.2	9.0	11.0
8	3.23 Mischmetal	13.0	10.0	12.3
9	6.33 Mischmetal	15.5	12.0	14.8

Relationships Between Germanium and Cadmium In the Electrolysis of Zinc Sulphate Solutions

by S. T. Ross and J. L. Bray

The paper provides electrometallurgical data on the problem of germanium removal from zinc sulphate solutions. Germanium traces have caused much concern to the zinc refiner. Confirmatory evidence of interaction between germanium and cadmium is presented. Statistical analysis of data expands its significance and enhances its value. Further research is outlined.

THE literature contains many references to the effects of trace amounts of germanium in the production of electrolytic zinc. One of the authors had experience with this troublesome element as early as 1917 at Trail, B. C. In 1929, Tainton and Clayton[1] reported that concentrations of as little as one part per million of germanium were sufficient to cause serious losses in current efficiency. Liddell[2] reported that trace amounts of germanium cause marked lowering of the hydrogen overvoltage of electrolytic zinc cells, so that commercial production was impaired. Bray[3] recorded the history of germanium in relation to electrolytic zinc production, noting that concentrations below 10 ppm have been found to yield low current efficiencies and copious hydrogen evolution. Koehler[4] stated that germanium "when present to the extent of a small fraction of one part per million per liter, causes serious evolution of hydrogen with a corresponding reduction in current efficiency."

Recently, however, S. W. Ross[5] reported, from Risdon, Tasmania, that "in the course of leaching ... dissolved traces of germanium ... if not removed almost completely ... increase the reversion of cadmium during the filtration of the copper-cadmium precipitate and reduce the current efficiency during subsequent analysis." The copper-cadmium precipitate referred to is the residue from the zinc-dusting purification of zinc sulphate leach solutions.

In the face of such conflicting testimony and with the increasing industrial importance of pure germanium and zinc it was decided to investigate the relationship between cadmium and germanium. Furthermore, other work by the authors showed certain discrepancies to exist in the theories of Tainton, et al. In the laboratory, without marked efficiency decreases, the authors have deposited zinc successfully from solutions containing as high as 1 g per liter of germanium. This could be done only when there was no cadmium present.

Preliminary investigations of the suspected relationships were carried out by means of emission spectrographic analysis using a beryllium internal standard. Several solutions containing 100 g per liter of zinc, as zinc sulphate, and 1 g per liter of cadmium, as cadmium chloride, were prepared. These concentrations were on the order of those obtained during a commercial low-acid leaching process. Varying concentrations of germanium were added to these solutions so that the range of 0.0000 to 0.5000 g per liter of germanium was covered. A 250 ml sample of each solution was agitated with 2.5 g of zinc dust for 30 min, filtered, and the filtrates were examined spectroscopically. Qualitative evidences of cadmium traces were found in those filtrates which originally contained above 10 ppm of germanium. Reliability of the analytical method did not permit quantitative investigations since cadmium determination in the concentrations present in zinc-dusted solutions lacks sufficient sensitivity for reproducible results.

Table I. Current Efficiencies Obtained at 0.0000 and 1.5000 G per Liter Cadmium Concentrations

Ge Concentration,* G per Liter	Cd Concentration,* G per Liter	Efficiency, Pct
0.0000	0.0000	94.270
0.0010	0.0000	94.849
0.0050	0.0000	92.649
0.0075	0.0000	94.039
0.0100	0.0000	96.084
0.0000	1.5000	93.460
0.0010	1.5000	95.158
0.0050	1.5000	92.148
0.0075	1.5000	91.260
0.0100	1.5000	94.548

* Cd and Ge concentrations shown are those existing before zinc-dust purification.

As a consequence of the inability of the investigators to obtain acceptable results through direct quantitative analysis, an indirect approach was devised. This indirect method involved a study of the current efficiency, in a model zinc cell, as a function of the concentrations of cadmium and germanium. Variables such as cell temperature, voltage, current density, anode spacing, relative electrode area, degree of agitation, cathode preparation technique, time, acid concentration, and solution volume were held constant.

Fig. 1 shows the cell used. The current was fur-

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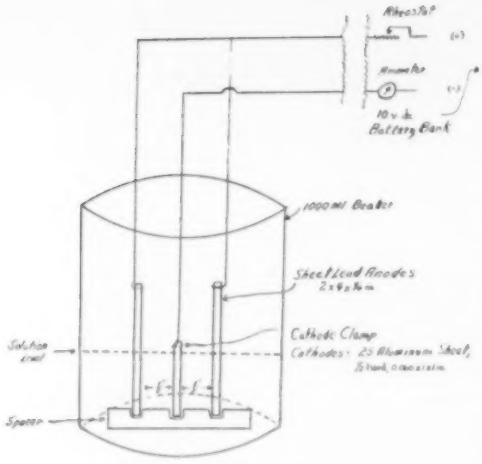

Fig. 1—Model zinc cell.

nished by a 10 v storage battery bank. The anodes were high purity sheet lead, approximately 2x4x¼ in. The cathodes of 2S aluminum alloy sheets were 0.060 in. thick, ½ hard, cut into 1-in. squares. The anodes were separated by a wooden spacer which had been dipped in paraffin to prevent possible side reactions from occurring. The current was kept constant at 0.425 amp for each run—a current density of approximately 30 amp per sq ft. Each run was accomplished at room temperature without agitation. Each solution contained 100 g of zinc per liter, as zinc sulphate, and each run was made with a 250 ml volume of solution. Each cathode was degreased with trichloroethylene before electrolysis. Each solution was treated with 2.5 g of zinc dust for 30 min, with agitation, and filtered before electrolysis. Measurements were taken of the weight of each cathode before and after electrodeposition, and the weight of zinc deposited was obtained as a difference. The current efficiency of each run was calculated according to Faraday's law.

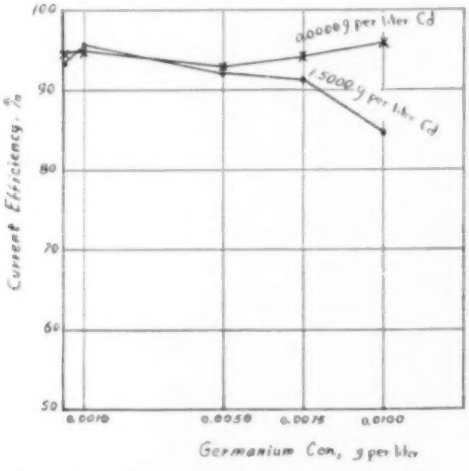

Fig. 2—Current efficiencies at 0.0000 and 1.5000 g per liter Cd levels.

Experimental Results

Table I lists the analyses, before zinc dusting, and current efficiencies obtained from solutions varying from 0.0000 to 0.0100 g per liter of germanium at the 0.0000 and 1.5000 g per liter concentration levels of cadmium. The time of each run was 30 min. Fig. 2 shows that the current efficiency, when plotted against the germanium concentration, tends to drop off rather sharply with increasing germanium content at the 1.5000 g per liter level of cadmium concentration, while remaining relatively constant at the 0.0000 g per liter cadmium concentration level.

Expanded Data: For evidence of the interaction between cadmium and germanium, the data were expanded and an analysis of variance was performed. For cadmium concentrations of 0.0000 to 2.5000 g per liter in combination with germanium contents of 0.0000 to 0.1000 g per liter, three plating runs were made for each zinc sulphate solution. The runs were of 60, 30, and 15 min duration to obtain replication of the statistics, as well as to investigate the variable of plating time. All other factors were held constant, as described before. Table II shows the tabulated results of 75 runs made in random order. Randomization was achieved by assigning numbers 1 to 75 to each run, and performing each run in the order in which its number appeared in a table of random numbers as prepared by Fisher and Yates.[6] Randomness was desired to remove as much of the cumulative effects of error as possible (e.g., possible effects due to a build-up of anode reaction products in the solutions, etc.).

Table II. Effect of Germanium and Cadmium on Current Efficency[a]

Cd, G per Liter	Time, Min.	Ge, G per Liter				
		0.0000	0.0010	0.0050	0.0075	0.0100
0.0000	60	96.971	94.540	94.270	90.122	95.273
	30	94.270	94.849	92.649	94.039	96.084
	15	92.997	94.077	95.238	89.524	92.379
1.0000	60	96.991	94.347	94.223	92.186	87.402
	30	95.505	93.730	88.521	91.878	82.269
	15	94.694	92.071	90.373	89.202	88.058
1.5000	60	95.119	94.521	93.317	92.206	84.321
	30	93.460	95.158	92.148	91.260	84.546
	15	95.003	94.154	88.058	90.681	84.893
2.0000	60	92.997	94.965	92.977	84.276	88.135
	30	94.965	93.614	91.341	89.833	82.688
	15	93.769	94.077	90.604	86.051	83.712
2.5000	60	95.659	95.158	92.611	88.289	87.446
	30	94.077	95.505	91.120	89.138	83.418
	15	94.926	94.617	87.980	87.517	85.125

[a] These statistics were obtained from conversion of the weights of deposited zinc through the application of Faraday's law. The statistics are current efficiencies in percent. Percent current efficiencies = $\frac{\text{Wt Zn} \times 1157.636}{\text{Time in min}}$. Cadmium and germanium concentrations shown are those existing before zinc-dust purification.

Analysis of Variance: An analysis of variance was performed on the data of Table II using the method of Freeman.[7] Essentially, the method consisted of obtaining the variance due to each factor, or combination of factors, and comparing it for significance with the variance due to error.

The significance of the interaction of cadmium and germanium concentrations was thus established. By indirect means, it substantiated the fact, only

hinted at by the spectrograph, that the chemical interaction of germanium and cadmium is of significance in consideration of electrolytic zinc cell problems. Analysis of variance showed that the interaction of germanium and cadmium was of such statistical importance that it must be regarded as a factor in the variation of cell current efficiencies due to other than random causes.

Significance of Difference: To obtain further evidence of the relationship between germanium and cadmium, the solutions on the 0.0000 and the 1.0000 g per liter levels of cadmium concentrations were investigated in a somewhat different manner. A test for the significance of the difference of the means of these two groups of data was made. The methods of "Student"[8] and Fisher[9] were followed.

Such calculations indicated that a statistically significant difference existed between mean values of the data. The primary assignable cause of that difference was variation of the cadmium concentration. Such random errors as may have been introduced by slight fluctuations of other variables were minimized by the method of calculation.

Summary and Conclusions

The significance of difference and analysis of variance tests as performed on the above data substantiate the claim that definite interaction exists in the zinc cell between cadmium and germanium concentrations. Germanium alone, within normal operating limits, does not cause large current efficiency losses. Rather, this research indicates that the adverse effects of germanium are notably enhanced by the presence of cadmium, and that the presence of germanium in leach solutions of the commercial zinc sulphate type precludes the complete removal of cadmium from them. This leads to further questions, as yet unsettled. What, if any, are the effects of the interactions of other impurities such as arsenic, antimony, bismuth, and lead, in the minute quantities found present after purification by present methods? How is the cell overvoltage affected by these interactions? What is the physical-chemical answer to the existence of such interactions? These are now being investigated in this laboratory.

While the answers to these questions are of academic interest, the commercial picture remains the same. Regardless of the nature of the interactions, germanium and cadmium must be removed in sufficient quantity before efficient electrowinning of germanium-tainted ores can be accomplished. It does not matter to the zinc producer whether germanium causes efficiency losses directly, or whether germanium and cadmium cause efficiency losses. In either event, the difficulty is there and a remedy must be found.

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Technical Note

Deformation Texture of Cold-Drawn Copper Wire

by Walter R. Hibbard, Jr.

BACKOFEN[1] reported recently that "the deformation texture of cold-drawn OFHC copper wire, after a reduction in area of 97.3 pct, may still be described as a composite of [111] and [100] directions aligned parallel to the wire axis." In the introduction, he indicated that this was in contrast to the work of Hibbard,[2] who reported a single [111] texture after a reduction of 96.4 pct. Unfortunately Backofen stated that this was a reduction in area when actually it was a reduction in diameter, as is clearly stated in the reference. Moreover, the results of Backofen are in complete agreement with the results of Hibbard. Backofen's 97.3 pct reduction in area is an 83.3 pct reduction in diameter, after which he found a double [111] and [100] texture with the former predominating. Similarly, Hibbard,[2] after an 86 pct reduction in diameter found a double [111] and [100] texture with the former predominating. Hibbard, however, when he drew the wire further to 96.4 pct reduction in diameter, found primarily a single [111] texture as illustrated by Fig. 2 of ref. 3. Here also, Hibbard[2] reported evidences of the [100] recrystallization texture found by Backofen. It might also be pointed out that Backofen not only drew his wire 97.3 pct reduction in area but also etched them over 99 pct reduction in area from 0.125 to 0.01 in. diam. Hibbard's wires were drawn directly to size.

In summary, the deformation texture of cold-drawn copper wire still may be described as primarily a single [111] texture after a sufficient amount of drawing, such as 96.4 pct reduction in diameter.[3, 4]

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[1] W. A. Backofen: JOURNAL OF METALS (March 1951), *Trans.* AIME, p. 250.

[2] W. R. Hibbard, Jr.: *Trans.* AIME (1949) **185**, p. 598; JOURNAL OF METALS (Sept. 1949).

[3] W. R. Hibbard, Jr.: *Journal* Inst. of Metals (London) (August 1950) p. 581.

Electric Furnace Melting Of Copper at Baltimore

by Peter R. Drummond

THE final casting of refined copper has been restricted for generations by the following sequence of operations: Filling the reverberatory furnace, melting, skimming, blowing or flapping, and poling. The hoped-for 24 hr cycle, producing 300 tons or more, has been taken up largely with the necessary but time-consuming tasks of cleaning the bath, sulphur elimination, and in turn removal of excess oxygen to produce tough-pitch copper. Incidental to comparatively slow melting under combustion gases, copper oxides react with the furnace lining, and the slag so-formed must be completely recycled.

The three-phase arc furnace has eliminated some of the cycle stages, and telescoped the remainder into a continuous operation. Electrical energy, supplied to graphite electrodes enclosed in high grade refractories, rapidly melts copper cathodes and sustains a stream of metal, containing approximately 0.01 pct oxygen, without contamination from fuel.

The arc was struck on the first large electric furnace for melting copper in the United States on April 13, 1949. The earliest use of this type of furnace was at Copper Cliff, Ont., in 1936, and an admirable description of their installation has been published.[1] Copper, melted in the Baltimore furnace, is used to cast billets, and the installation differs somewhat from the Canadian, as will be described.

The arc furnace is a heavy-duty, three-phase furnace, holding 50 tons, the general outline of which appears on Fig. 1. The steel shell is 15 ft ID with a bottom radius of 14 ft 2 in. The roof, separate and distinct from the body, consists of a 15-ft water-cooled, cast-steel ring of the same outside diameter as the furnace. The center line of the furnace lies 9 ft 6 in. from that of the trunnions, permitting a 5° backward tilt for skimming, and a 40° maximum nose tilt forward for complete draining. Normally, the furnace overflows by displacement, and the use of the forward tilt arrangement is restricted to covering charging delays.

The charging slot, 3 ft 8 in. x 5 in., lies on the north center line, the tap hole on the south, and the 30x30 in. skim door 45° to the west of the slot.

The original 20-in. graphite electrodes were replaced with 14 in. in December 1949. Three conventional direct current winch drives, governed by electrical controls, position each electrode which has individual mast supports and counterweights. An independent circulation supplies cooling water for the electrode glands, the roof ring, charge slot, and the skim door frame.

[1] *Trans.* Canadian Inst. of Min. and Met. (1946) **49**, pp 199-222.

Arc Furnace Refractories

Hearth: Fused-in monolithic bottoms had been used in copper arc furnaces, installed prior to April 1949. These consisted of thin layers of periclase, successively fused in place over preliminary brick courses. Heat was obtained from the arc, using a T-like arrangement of broken electrodes resting directly on the periclase to be fused. The operation, taking weeks to perform, was very expensive. The chemically-bonded magnesite-brick bottom, installed at Baltimore, was the first of its kind and a radical departure from previous practice.

It consists of a 1 to 6-in. layer of castable refractory laid on the steel shell, modifying it to a 12 ft 2 in. bottom radius. Two courses of 9x2½-in. fireclay straights and keys follow.

The third course is made of 9-in. magnesite blocks of special shape to form circles of an inverted arch. It was started by a four piece keystone with skewbacks forming the outer course. The fourth course also started on a central keystone, or button, of four 90° segments, 12 in. diam x 13½ in. deep, and continued with 13½-in. blocks. Skewbacks at the shell completed the course to produce a horizontal surface for the side walls with a single course of No. 2 arch fireclay against the steel.

Dry chrome-magnesite cement was brushed over each course after laying, and a 1-in. expansion space between the brick and the shell was filled with the same mixture. The total bottom thickness, excluding the castable material, was 5 in. of clay plus 22½ in. of chemically-bonded magnesite.

Tap Hole: A 5-in. OD and 3-in. ID silicon-carbide tube constitutes the tap hole and is set tangential to the upper course of the furnace bottom. Molten metal fills the tube when the furnace is level and filled to capacity.

Side Walls: The lining, against the shell, consists of a 9x4½x3 in. soldier course of fireclay, using straights and No. 1 arches to turn the circles. A second soldier course of 9x4½x2½-in. fireclay was laid in a somewhat similar fashion.

Three courses of 13½x6x3 in. and 9x6x3 in. of final magnesite, laid flat, completed the lining, using Nos. 1 and 2 keys to turn the circles. Cardboard spacers were placed between every two bricks in horizontal courses, and a thin coat of chrome-magnesite cement filled the joints between the firebrick and magnesite. A sprung-arch spanned the skim door with jambs of suitable magnesite shapes.

Charge Slot: The slot is 3 ft 8 in. wide x 5 in. high. A silicon-carbide sill of special shapes has a 30° slope to allow cathodes to slide easily into the bath. The original arch was flat, and composed of Nos. 1 and 2 wedge magnesite with a 6-ft radius. It projected 5 in. over the sill, and, being a flat arch, gave an 18 15/16-in. opening between the inner edge and the metal line. The whole assembly was later raised 9 in., and the flat arch replaced with an arch, the lower edge of which maintained the 5-in. width from the outer to inner edges as shown in Fig. 2. A water-cooled, cast-copper jacket protects the steel shell behind the slot.

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Roof: A single course of fireclay skewbacks of special shape encircle the water-cooled ring. The remainder of the roof embodies standard sprung-arch construction, using bonded 9-in. magnesite of 3 and 2½-in. arches, straights, and wedges with special shapes as required to turn the circles, and with cardboard expansion joints between every fifth brick. The three electrode openings and a vent are turned respectively with 13½x4½x2½ in. and 9x 4½x2½ in. magnesite arches.

Launder: A 30-ft steel-framed launder, a cross-section of which appears on Fig. 1, connects the arc furnace with a low frequency induction furnace. Three 9x4½x2½-in. silica insulating brick line the bottom with a course along each side, laid flat, leaving 2-in. side spaces which are both filled with loose silica insulation. Suitable fireclay shapes support the central silicon-carbide V channel, formed with one 1½-in. split laid flat and two 9-in. splits at a 60° angle, giving a roughly equilateral channel 9 in. deep x 10 in. wide at the top. Joints are filled with silicon-carbide cement. Courses of clay brick, two of 12x12x2 in. and one of 12x6x3 in. cover the channel.

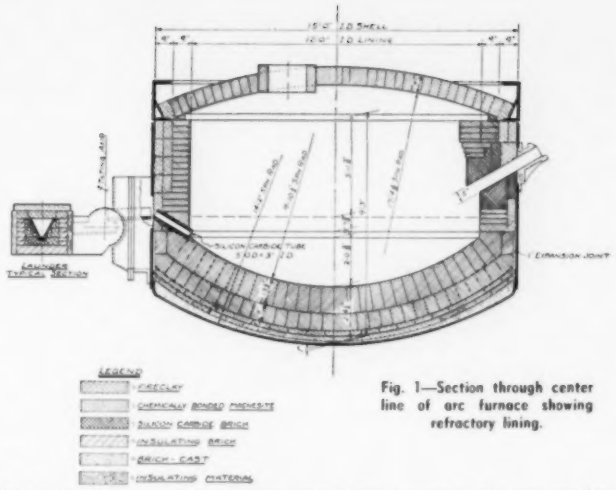

Fig. 1—Section through center line of arc furnace showing refractory lining.

Induction Furnace: This holds about 5 tons, appears in outline on Fig. 3, and serves merely as a reservoir between the arc and the casting ladles. Power control will be described under electrical equipment. Metal enters the unit from the launder through a 6 in. OD x 4 in. ID silicon-carbide tube inserted through one furnace trunnion. The furnace pours into casting ladles through a similar tube set at an angle to allow complete drainage without going beyond 90° from the vertical.

The unit comprises two sections: A body and separate induction slot. A steel casing constitutes the vertical shell and is lined with one soldier course of 4½-in. insulating firebrick and a course of chemically bonded 9-in. magnesite keys. The steel roof cover is filled with a castable refractory and clamps to the shell. A rammed 9-in. Mullite bottom is connected with the slot proper through an opening 24½x6 in. tapering to 21½x3 in.

The induction unit bolts to the foregoing. Each unit is rammed with Mullite, containing 6 pct moisture. This requires considerable technique, and once started, is carried to completion in 10 to 12 hr without interruption. After ramming, the units are heated electrically and dried before being put into service.

Two thermocouples, lying against the metal core bushing of the primary induction unit, connect with a recording potentiometer, by means of which core failure can be predicted. An independent 750 psi hydraulic system is used to tilt the induction unit for pouring about one ton of metal in 34 sec.

Charging Machine: Cathodes, to be charged to the arc furnace, are piled 20 high on pallets and travel by gravity on rollers to a shear, where the loops are removed. The cathode is then pushed into the charging machine magazine, which constitutes a novel feature of the installation.

The storage magazine consists of two endless parallel chain conveyors, mounted on a frame at 60° from the horizontal, to hold the cathodes. The chains carry a series of parallel plates, which form slots, and as a cathode comes to rest on one of them, its weight actuates a switch, energizing the drive motor to move the magazine one position upwards and so insure the presence of one sheet at a time in each slot. Fully loaded, the magazine holds approximately a 30-min supply for the furnace, and one man per shift can handle all charging into the furnace.

An elevating mechanism is interposed between the storage magazine and the furnace charging slot. This descends on tracks until two hooked members intercept the first closed pair of magazine gates, holding the topmost cathode. The members energize suitable relays, stop the elevator, open the gates allowing the cathode to slide into the elevator, and, by automatically reversing the drive, return the carriage to the charging position.

A timer, which can be set to charge cathodes at any desired rate, controls two more or less simultaneous actions. It opens the furnace door and at the same time actuates a pusher which thrusts the cathodes through the slot. The ram withdraws, the furnace door closes automatically, and the elevator drops to continue the cycle.

Electrical Equipment: The local electric utility company supplies power over a three-phase 60-cycle, 13.8 kv overhead line supported on wooden poles and pin insulators. The line terminates 100 ft from the furnace substation, where it changes to a three-conductor leaded cable laid underground in fiber ducts.

The two-story furnace substation is of fireproof construction in conformity with the local building code. The first floor contains a six-section, high-voltage, metal-clad oil circuit breaker switch gear, station control battery, a necessary charging motor generator set, a furnace-rotating regulator set, and one six-circuit three-phase 440 v free-standing, metal-clad air circuit breaker switch gear serving arc furnace equipment. The second floor carries: one 250 kva—13.8 kv primary to 480 v secondary self-cooled, oil-insulated, single-phase, 60-cycle transformer for the low frequency induction furnace; one 6000 kva—13.8 kv primary to 85 to 225 v secondary,

Fig. 2—Present charging slot.

water-cooled, oil-insulated, three-phase, 60-cycle transformer with tap changer for the arc furnace; and one 750 kva—13.8 kv primary to 480 v secondary, self-cooled, oil-insulated, three-phase, 60-cycle transformer serving arc furnace equipment.

The transformers stand directly above their respective oil circuit breakers and are wired with single conductor, varnished-cambric, flameproof cable through fiber ducts enclosed in steel. The floor is constructed to form a liquid-tight basin to take care of a possible transformer tank failure.

The arc furnace transformer is in line with the vertical center line of the furnace and at sufficient height to minimize the heavy rigid secondary copper buswork and to provide clearance and free movement for the flexible cable loops between the bus and the electrode mast arms. The bare copper cables, connecting the bus and mast arms, consist of twenty 1,500,000 circular mil and twelve 1,750,000 circular mil cables per phase.

The arc transformer secondary is connected in Y and the primary in delta. The primary taps permit the following secondary line to line volts: 225, 208, 190, 173, 156, 147, 130, 120, 110, 100, 90, and 85. At the present time the furnace is operated on 190, 173, 156, and 130 v.

The furnace operating control panel is flush with the station wall, and the back is readily accessible for inside repairs through a door adjacent to the panel. The main initiating control for the charging machine is on the same panel, in addition to conventional instrumentation and arc furnace controls.

A 12-lantern semaphore occupies a position to one side of the operating panel, and a solenoid-operated air whistle attracts the operator's attention to: 1—Tripping of any of the substation high voltage breakers, 2—power failure on the 250 v dc supply exciting either the rotating regulator or the electrode winch motor, 3—overheating of the arc furnace transformer, 4—low transformer oil levels, 5—power failure on the induction unit, 6—cooling fan failure, 7—high arc furnace side wall temperatures, 8—charging machine failure, and 9—failure of station control battery charging equipment.

A silicon-carbide target tube is set flush with inner side wall lining of the arc furnace, and a radiation pyrometer, sighted on this, indicates side wall temperatures which are recorded continuously. An adjustable contact-making device connects the recorder with the semaphore.

The low voltage, free-standing, metal-clad switch gear and controller for the induction furnace unit stands adjacent to the casting platform. This houses the main air circuit breaker, tapped autotransformer, power-factor correction capacitators, manual presetting tap switches, and magnetic solenoid tap changing contactor. Indicating power-factor and kilowatt meters, furnace molten metal electronic temperature recorder and controller, and furnace inductor core sleeve electronic temperature recorders are set flush on front of the switch gear cubicle.

The inductor core is rated 100 kva, the autotransformer at 125 kva, 460 v, and is high tapped at 460, 440, and 380, with low at 250, 200, and 150. The manual selector switch preselects any one of both the high and low tap voltages. Then, the two solenoid-operated magnetic switches automatically control the furnace power input from the preselected taps. These, in turn, are dictated by electronic control received from the radiation pyrometer sighted on a silicon-carbide tube submerged in the metal bath.

The furnace currently operates on the 380 v high tap and 250 low, providing a power input of 65 and 30 kw respectively at 85 pct line power factor.

Seasoning: The brick hearth embodied a radical departure from previous practice, so, details of preheating and some history of the lining follow as contributory to the success of the furnace bottom.

Drying of the brick bottom began at 1:40 p. m., April 4, 1949, and the furnace was slowly brought to 2070°F by 7:20 a. m., April 11 by the use of an oil burner. The rise in temperature was controlled carefully by means of a thermocouple lying on the hearth with lead wires through the tap hole. The average rise was 11.8°F per hr.

After removing the burner, five tons of starting sheet scrap were charged. Six tons of ingots were then thrown on the cushion of scrap and the burner replaced. By 4 p. m. of the same day the charge was flat and the wall temperature 1900°F. The furnace was rocked back and forth intermittently until 11:10 p. m. to allow the molten metal to fill the interstices between the brick, the burner was then removed, and the furnace drained.

By 12:45 p. m. a second addition of 8.2 tons of starting sheets was charged. This was molten by 4:30 a. m., April 12, and ingots were then charged. By 9:15 a. m., 30.8 tons of ingots had been added. The charge was flat by 10:10 a. m., and the wall temperature 2020°F. Firing continued until 7:45 a. m. of the following day to raise the metal temperature. The burner was removed, and the electrodes lowered into the furnace. The side walls had reached 2120°F, and the arc was struck at 8:25 a. m. Power was used intermittently to familiarize the operators with the controls until 4:32 p. m. when cathode charging started.

The distinctive difference between burned-in bottom practice and the foregoing is that in burning in a bottom the arc is struck over a bare hearth whereas the brick bottom has never been subjected to direct radiation and possible local overheating. The wash-out charge made a copper-bonded monolith of the brick by allowing the metal to penetrate to a depth where it naturally froze, and the preliminary melt of 40 tons under oil assured that the bottom did not attain a temperature above that of the bath.

On Aug. 6, 1949, after 120 days of operation, the furnace was drained and cooled slowly, primarily

to replace the charging slot, the reason for which is explained below. Examination of the bottom at that time showed a slight build up of approximately ½ in. except for the central starting button of the upper course which had spalled to a depth of 2 in.

No repairs were made to the bottom, but a segment of the side wall, amounting to about one quarter of the circumference and including the skim door and charging slot, was replaced. A hot-metal charging slot was cut in the wall near the tap hole, and since then molten copper from the reverberatories has been used for the initial filling.

Charging Slot: The charging slot has been the cause of considerable delay. Copper accretions collect gradually in the opening, causing cathodes to jam. These accretions may be back splash from cathodes, metal surges caused by the arc, or a combination of both.

Details of the slot were presented in the general description, but it is noted again that the height of the opening increases from 5 in. at the shell to 18 15/16 in. at the inner face. This aperture facing the electrodes appears to act as an open trap for splash, and a change was made early in June 1950 to improve this condition.

This improvement consisted of raising the charging slot 9 in. above its previous location. In addition to raising the slot, a silicon-carbide arch, which maintains the 5 in. height throughout, was installed. The new slot appears on Fig. 2 and, as can be seen, it overhangs and partially protects the lower sill from splash. The charging delays for jammed cathodes and slot cleaning have been reduced greatly.

The silicon-carbide sill still presents a problem as this material quickly oxidizes. There is apparently a reaction between the oxides of copper and the carbide, as boiling can be seen around the lower edge of the sill. A periclase brick sill will be tried at the next repair, but the furnace has operated successfully for months with little or no sill brick.

Quality Control of Metal: Delivery of good quality cathodes leaves control of arc furnace metal dependent on the three elements: Oxygen, sulphur, and iron. This resembles reverberatory practice, but manipulation differs. The three elements are dealt with in order.

The arc furnace is vented by a 9-in. diam circular opening, six courses in from the side of the roof. An open bonnet, a few inches above the aperture is connected to a 5500 cfm fan. Regulation of air entering the furnace is obtained by changing the size of the roof vent with a movable brick cover.

The operators take two samples each hour, one from the arc furnace tap hole and one from the induction unit. The physical laboratory determines oxygen optically on cubes made from the samples and reports the results to the furnace foremen. Oxygen ranges from a trace to 0.02 pct with an ideal of 0.01 pct. The furnacemen regulate the roof vent in accordance with the analyses.

Sulphur could originate from the electrodes, the furnace lining, or the cathodes. Sampling and analysis of each electrode shipment has shown no sulphur. Chemically-bonded magnesite brick contains sulphates. As a result excess sulphur shows up for a time after a repair, but drops rapidly in a few hours; and the sulphur content soon becomes normal.

Sulphur control, therefore, centers on maximum removal of the sulphates and sulphuric acid from

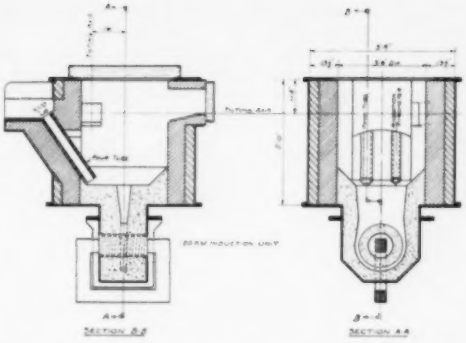

Fig. 3—Induction holding furnace for copper, 5-ton capacity, 100 kva.

the cathodes as they come from the tanks. This, obviously, is a washing problem, and sulphur removal has evolved along the following lines. The tank house has been equipped with twin dip tanks of sufficient size to take a whole lift of 40 cathodes and to allow complete submergence. Operators fill both tanks with fresh water before pulling starts and add 1.5 pt of a sulphate-free detergent to the first, and 1 pt to the second tank. Racks of cathodes are submerged, loops and all in the first tank, and soaked 2 min to dissolve or loosen crystals which may have formed within the loop. After lifting, the rack is held for half a minute to drain, which is the chief function of the detergent as it gives a better run-off. Next is a quick rinse in the second tank and the water sprays on the unloading machine.

Crystalline material within the loop has proved most difficult to eliminate. While the shears cut off the loop and upper 10 pct of the cathode, experience has shown that sulphates, if not removed from the loops in the dip tanks, slowly dissolve and run back over the body of the sheets while still wet.

Iron originates from the same sources as sulphur. It has proved to be negligible in each shipment of electrodes to date. In refractories, iron control becomes more complex. Our experience has been that the iron content of refractories, provided they remain in place in either the hearth, walls, or roof, is not serious. However, iron is absorbed immediately by the bath if it becomes covered with spalled brick.

Chemically-bonded magnesite brick contains upwards of 10 pct total ferrous and ferric oxides. A chrome-magnesite roof, installed in June, carries somewhat more. Similar to sulphur, iron shows up in the first hours after relining. During the present campaign, however, and in spite of the higher iron in the roof brick, the June through September monthly composites contained 0.0015, 0.0012, 0.0014, and 0.0010 pct iron respectively, which are satisfactory values.

Slag: Slag formation varies directly with accidental or deliberate additions to the bath. Because of the very refractory character of the furnace lining, the skimmings should not be termed slag, as they consist of semifused crusts impregnated with copper shot and oxides. The analysis of the September skims was: Cu, 21.71 pct; Fe_2O_3, 2.86; Al_2O_3, 3.89; SiO_2, 20.00; CaO, 4.68; MgO, 33.28; and Cr_2O_3, 8.90. Ignoring the copper, the remainder corresponds to

an accidental mixture of roof and wall brick plus a minor amount of magnesite cement.

Operation in General: Both furnaces operate around the clock, except for one prearranged shutdown each week for repairs. This has gradually evolved as part of the routine and lasts for an hour or so.

The shift foremen enter on a special report delays in the furnace charging and the exact cause therefor. An average of a three-month period in the summer of 1950 indicates 1.6 pct lost time for mechanical breakdowns, 0.2 pct for electrical, 9.2 pct for slot cleaning, and 4.3 pct for operational delays including the weekly planned shutdown.

Copper build-up on the slot remains the largest single source of lost time, and modification of the slot is further projected to overcome the difficulty. Operating delays include slipping or adding electrodes, infrequent stoppages for skimming of the bath, and miscellaneous troubles.

The arc furnace is rated at 20 tons per hr. This rate has not been reached yet over an extended period; the best daily tonnages have been approximately 15 tons per hr, but over shorter periods the rated capacity has been approached.

A low power factor was obtained from the original 20-in. electrodes, and these were changed to 14-in. in December 1949, resulting in a rise in the power factor to over 70 pct. Characteristics of the larger electrodes were current surges, excessive agitation of the bath, a 50 to 60 pct power factor, but comparatively cool side walls and roof at any given bath temperature, and slightly less power consumption per ton melted. The smaller electrodes reduced current surging, and raised the power factor, but the walls and roof were relatively hotter for the same metal temperature, and the electrodes operate at low red heat between the clamps and the roof ring because of increased IR loss.

Electrode consumption in May, August, and September 1950, averaged 3.96, 4.20, and 3.96 lb per ton respectively. The intervening months were higher because weekend shut-downs raised wastage by consuming electrodes during holdovers when no copper was being melted.

Arc Furnace Power Consumption: During weekend holdovers in the summer of 1949, it was established that about 300 kw per hr was required to maintain the temperature in a full furnace bath when no cathodes were charged. This constant is the furnace heat loss, and continues at all times; therefore, on a per ton basis it is proportionally more or less according to the casting rate. At 5 tons per hr the loss, expressed as power, would be 60 kw-hr per ton, 30 kw-hr per ton for 10 tons, and 20 kw-hr per ton at 15 tons melted per hr.

According to the best thermal data,[5] molten copper at 2300°F contains 182.8 lb cal per lb, which is equivalent to 192.8 kw-hr per ton. If the heat loss input of the last paragraph is added, it gives 253 kw-hr per ton for 5 tons per hr, 223 for 10 tons, and 213 for 15 tons.

These figures are somewhat low on a current operating basis for two reasons. First, heat losses were based on a new furnace lining and roof, and the caloric loss will be higher with an old lining or thin roof. Second, they were also based on 20-in. electrodes, and as the 14-in. operate at low red heat above the furnace roof, this IR loss would increase the 300 kw per hr loss. Power consumption currently ranges between 250 and 280 kw-hr per ton melted, depending on the casting rate.

Temperature Control: A multiplicity of temperature readings are recorded automatically or read at stated intervals and entered on the shift reports. Three equally spaced, dial, gas thermometers are inserted through the arc furnace shell to contact the brick slightly below the metal line. Under the charging slot, shell temperatures are taken once a shift with a surface-contact thermocouple. A thermocouple is embedded in the brick bottom at the apex of the inverted dome of the hearth. The temperature at this position is also recorded once a shift.

All the foregoing were installed originally to signal bottom failure, and the foremen record the temperatures at the start of each shift. To date, no failure has occurred, and the readings have had little significance. At the end of the last preheating in June 1950, the thermocouple in the bottom of the hearth recorded 320°F, rose to 400° in two weeks, and reached 420° after five months.

A radiation pyrometer with the internal end of the target tube flush with the inner face of the arc furnace wall automatically records the wall temperature. This was installed as a safeguard immediately after observing that the 14-in. electrodes gave significantly hotter walls. The normal range lies between 2400° and 2500°F, but a limit of 2600° was established, and the power input is reduced when temperatures exceed the latter figure.

Arc furnace operators insert an immersion thermocouple in the tap hole every 15 min, and the result is recorded automatically on a chart. Typical readings over any one day would be a maximum of 2380°F, minimum of 2250°, and average of 2310°.

At the induction furnace a second radiation pyrometer, sighted on a tube terminating in the bath, records metal temperatures and automatically controls the power input. This is checked manually once an hour with an immersion thermocouple, and the normal range lies between 2180° and 2250°F.

During a 57-hr layover in 1949, it was established that a power input of 49 kw per hr was necessary in order to hold the induction furnace bath at an even temperature, with neither metal input nor output. The two operating taps are 30 and 65 kw-hr, and theoretical calculations based on the heat loss and a 15 ton per hr at 2300°F input, show that the lower tap would give a constant bath temperature drop of 14°F, and the higher a pick up 6°F. The metal, leaving the induction furnace is, therefore, in the neighborhood of 2200°F.

The function of the core-bushing thermocouple at the primary induction loop has been described. In addition, two gas thermometers are inserted in the cooling-fan discharge of the same bushing, and air temperatures are noted as an extra precaution.

Dust Loss: Copper, even at conventional reverberatory temperatures, has a slight vapor pressure, and under the much hotter arc, it becomes appreciable. A wet cyclone treats gases from the roof vent and charging slot. Total vaporization amounts to approximately 4 lb of copper per ton melted, of which the scrubber recovers about 85 pct. The lost fume is largely around one micron in diameter, and a small bag house is in process of being installed to collect it. The recovered dust is recharged into the reverberatories, as it is largely pure cuprous oxide.

[5] U.S. Bureau of Mines, *Bulletin* 371.

Technical Note

Metallographic Techniques for High Purity Aluminum

by Italo S. Servi and Nicholas J. Grant

SPECIAL polishing and etching techniques were developed during an investigation of the high temperature mechanical properties of high purity aluminum (99.995 pct Al).* Electrolytic polishing was done successfully in the following electrolyte: 5 ml perchloric acid (72 pct), and 95 ml glacial acetic acid.

No special precautions need be taken during the preparation of the electrolyte since no appreciable heat of mixing is evolved. Although the electrolyte is not an explosive, it is recommended that Jacquet's safety rules[1] be followed during the polishing operation.

A voltage of 25 to 60 v gives a good polish in about 2 min at room temperature after preparation on 3/0 metallographic paper. Most of the grain boundaries are visible under the microscope after polishing. Since the current is controlled essentially by the resistance of the bath, it is necessary to keep the anode-to-cathode distance as constant as possible.

Fig. 1—High purity aluminum. Electrolytic polish and etch as described in text. X1.5.

Accordingly, polishing of irregularly shaped pieces will be difficult. A cooling bath and a stirring system are advisable in order to keep the temperature of the bath uniform and constant.

Coarse-grained samples can be macroetched in a few seconds by lowering the voltage below 10 v. This is done after electrolytic polishing, without removing the sample from the bath, Fig. 1. The specimen can be repolished in less than 1 min by raising the voltage above 25 v.

The "galvanic etching" technique, which has been described elsewhere,[2] was found to be helpful not only for macroetching, but also for microetching coarse-grained specimens. In fact, the different orientations of adjacent grains provide good contrast at the grain boundaries, when the sample is observed under polarized light.

If the specimen is only partially etched, Fig. 2a, the grain boundaries can be located without completely destroying the appearance of the surface of the specimen. The unetched surface appears black under polarized light. Excellent color contrast is obtained by using a "sensitive tint" plate in the optical system of the microscope. In this case, the unetched surface has a magenta color, while the etched part of the sample assumes different colors varying from green to brown, according to the orientation of the grains.

Etch pits were produced on high purity aluminum by using the technique suggested by Lacombe and Beaujard.[3] Good results also were obtained by substituting 70 pct nitric acid for the fuming nitric acid recommended. This gave an etching reagent of the following composition: 70 ml nitric acid (70 pct), 50 ml hydrochloric acid (37.5 pct), and 3 ml hydrofluoric acid (48 pct). An example of the results is shown in Fig. 2b. The outline of the etch pits is revealed sharply if the specimen is observed under polarized light, as shown in Fig. 2c.

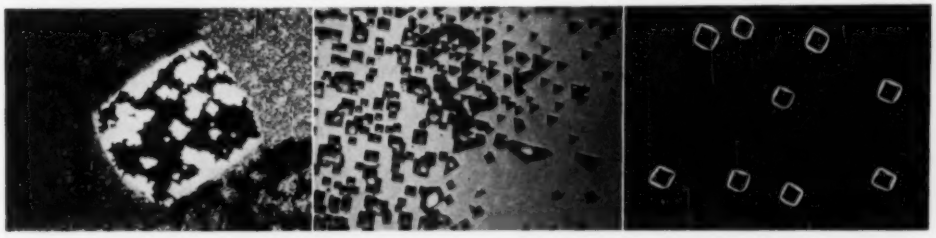

Fig. 2—High purity aluminum. Electrolytic polish in perchloric-acetic acid. a (left)—Partial "galvanic" etching in hydrochloric acid. Polarized light. X50. b (center)—Etched in modified Lacombe reagent for 30 sec at 9°C. X1000. c (right)—Etched in Lacombe reagent for 30 sec at 9°C. Polarized light. X500. Area reduced approximately 75 pct for reproduction.

These metallographic techniques are not suitable for the examination of commercially pure (2S) aluminum.

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* The high purity aluminum was kindly furnished by the Aluminum Co. of America.

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Technical Note

Origin of the Cube Texture in Face-Centered Cubic Metals

by Paul A. Beck

THE occurrence of the (100) [100] or "cube" texture upon annealing of cold-rolled copper has been much investigated.[1] The conditions favorable for its formation were found to be a high final annealing temperature[2] or long annealing time,[3] a high reduction of area in cold rolling prior to the final anneal,[4] and a small penultimate grain size.[4] The effects of penultimate grain size and of rolling reduction were found by Cook and Richards[5] to be interrelated in such a way that any combination of them giving lower than a certain value of the final average thickness of the grains in the rolled material leads to a fairly complete cube texture with a given final annealing time and temperature. Also, according to the same authors, at a higher final annealing temperature a larger average rolled grain thickness, i.e., a lower final rolling reduction, is sufficient than at a lower temperature. These somewhat involved conditions can be understood readily on the basis of recent results obtained at this laboratory.

Hsun Hu was able to show recently by means of quantitative pole figure determinations that the rolling texture of tough pitch copper, which is almost identical with that of 2S aluminum,[6] may be described roughly as a scatter around four symmetrical "ideal" orientations not very far from (123) [112]. In the case of aluminum, annealing leads to retainment of the rolling texture with some decrease of the scatter around the four "ideal" orientations, and to the appearance of a new texture component, namely the cube texture.[6] A microscopic technique, revealing grain orientations by means of oxide film and polarized light, showed that the retainment of the rolling texture is achieved through two different mechanisms operating simultaneously, namely "recrystallization in situ," and the formation of strain-free grains in orientations different from their local surroundings, but identical with that of another component of the rolling texture. Thus, a local area in the rolled material, having approximately the orientation of one of the four "ideal" components of the texture, partly retains its orientation during annealing, while recovering from its cold-worked condition, and it is partially absorbed at the same time by invading strain-free grains of an orientation approximately corresponding to that of another "ideal" texture component. The reorientation here, as well as in the formation of the strain-free grains of "cube" orientation, may be described as a [111] rotation of about 40°, see Fig. 1 of ref. 6. The preferential growth of grains in such orientations is a result of the high mobility of grain boundaries corresponding to this relative orientation.[7,8]

It appears very likely that in copper the mechanism of the structural changes during annealing is similar to that observed in aluminum (except for the much greater frequency of formation of annealing twins in copper). In both metals the new grains of cube orientation have a great advantage over the new grains with orientations close to one of the four components of the rolling texture. This advantage stems from their symmetrical orientation with respect to all four retained rolling texture components of the matrix; they are oriented favorably for growth at the expense of all of these four orientations. As a result, the growth of the "cube grains" is favored over the growth of the others, as soon as the new grains have grown large enough to be in contact with portions of the matrix containing elements of more than one, and preferably of all four component textures.

It is clear that this critical size is smaller and, therefore, attained earlier in the annealing process if the structural units, such as grains and kink bands, representing the four matrix orientations are smaller, i. e., if the average thickness of the rolled grains is smaller. Hence, for a given annealing time and temperature, a smaller penultimate grain size and a higher rolling reduction both tend to increase that fraction of the annealing period during which the above condition is satisfied. Consequently, the percentage volume of material assuming the cube orientation increases. The same is true also for increasing time and temperature of annealing when the penultimate grain size and the final rolling reduction are constant, since the average size attained by the new grains during annealing increases with the annealing time and temperature. For the same reason, at higher annealing temperatures a given volume percentage of cube texture can be obtained with larger rolled grain thickness (larger penultimate grain size, or smaller rolling reduction) than at lower annealing temperatures. The well-known conspicuous sharpness of the cube texture may be interpreted as a result of the fact that selective growth of only those grains is favored that have an orientation closely symmetrical with respect to all four components of the deformation texture and exhibit, therefore, a high boundary mobility in contact with each.

The effect of alloying elements in suppressing the cube texture, as described by Dahl and Pawlek,[2] appears to be associated with a change in the rolling texture. For face-centered cubic metals, such as copper, which do exhibit the cube texture upon annealing, the rolling texture is always of the type described above, i. e., scattered around four "ideal orientations" of approximately (123) [112]. The addition of certain alloying elements, such as about 5 pct Zn or 0.05 pct P in copper, has the as yet unexplained effect of changing the rolling texture into the (110) [112] type. This texture consists of two fairly sharply developed, twin related components. In such cases, as in 70-30 brass and in silver, the annealing texture again is related to the rolling texture by a [111] rotation of about 30°, however, because of the different rolling texture to start from, it has no cube texture component. At higher temperatures, both in brass[9] and in silver,[10] grain growth leads to a further change in texture: A [111] rotation of the same amount, but in reversed direction, back to the original rolling texture.

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In summary, it may be stated that the oriented growth theory of annealing textures readily explains, at least qualitatively, the various conditions and their interrelations thus far described in the literature, that affect the formation of the cube texture.

Acknowledgment

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Technical Note

Theory of Annealing Textures

by Paul A. Beck

IN several recent investigations[1-4] considerable evidence was accumulated to show the predominance in various face-centered cubic metals of a certain relative orientation, corresponding to a rotation of 30° to 40° around a /111/ axis, between a matrix with a strong single orientation texture and grains growing in this matrix.* This relative orientation was found to occur both in recrystallization and in coarsening, "secondary recrystallization", so that one is inclined to look for an explanation applicable in both cases.

The abundance of growing grains in the described orientations proves that suitable "nuclei" are present in the matrix material and that they have the capacity to grow. The scarcity of growing grains in other orientations may be explained in one of two ways. Either the number of nuclei or the rate of growth must decrease strongly for orientations deviating from that predominating among the growing grains, Fig. 1. Both the "oriented nucleation" and the "oriented growth" theory found support in the literature. Because the frequency of nuclei as a function of orientation is in most instances not amenable to direct experimental investigation, a definitive decision is difficult to achieve. However, it is now known with great certainty that the rate of boundary migration is strongly dependent on the relative orientation of the two grains meeting at the boundary and that the orientation favored by high boundary mobility closely corresponds to that predominating in most cases of recrystallization and coarsening.[5] Thus, it was found that, in general, the mobility is very low for boundaries between grains of nearly identical orientation, or for coherent twin boundaries. On the other hand, the boundaries between two grains of a relative orientation corresponding to a /111/ rotation of 30° to 40° have the highest mobility in face-centered cubic metals. If a large variety of nucleus orientations are produced

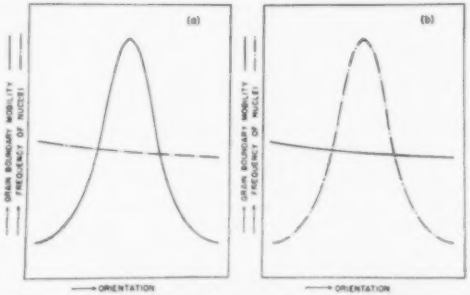

Fig. 1—Grain boundary mobility (solid line) and frequency of nuclei (dotted line) as a function of orientation according to (a) oriented growth theory and (b) oriented nucleation theory.

artificially by means of a highly inhomogeneous local deformation, nuclei close to the above orientation are found to grow fastest.[6-8]

In view of this evidence and of the fact that the preferred orientation relationship is the same in recrystallization and in coarsening, the oriented growth theory appears by far the more promising one. Since the origin of nuclei in primary recrystallization is certainly different from that in coarsening, the occurrence of the same orientation relationship in the two processes would be difficult to explain on the basis of oriented nucleation. Other advantages of the oriented growth theory are its capability of accounting for the often observed sharpening of the texture in coarsening,[9] and its suitability for explaining the role in the formation of the "cube texture" of the most important variables, such as the degree of rolling, the penultimate grain size, and the time and temperature of the last anneal.[7] No similarly consistent explanation of all these effects has ever been offered in terms of oriented nucleation.

An important problem in connection with the oriented growth theory is the following: In the cubic crystal system there are four /111/ axes and

* In a hexagonal close-packed metal, zirconium, for which sufficiently good data are available,[10] the reorientation upon recrystallization corresponds to a rotation of 30° around the basal plane normal. Therefore, it may be concluded that in both face-centered cubic metals and in hexagonal zirconium the reorientation in recrystallization corresponds to a rotation around the normal of a close-packed plane. In both cases the new orientation lies about half way between two orientations with low grain boundary energy, where the grain boundary energy may be assumed to have a maximum.

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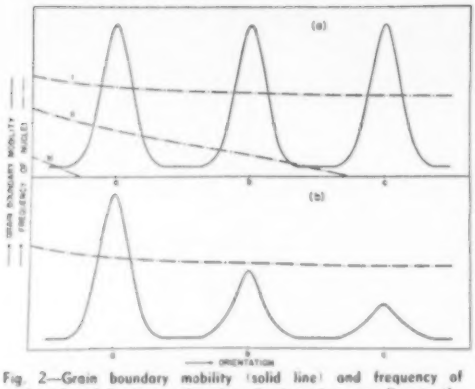

Fig. 2—Grain boundary mobility (solid line) and frequency of nuclei (dotted line) as a function of orientation according to the oriented growth theory. Certain orientations with high boundary mobility do not appear in the texture (a) because of scarcity of nuclei and (b) because the relative maxima of mobility have different values for the various crystallographically "equivalent" favorable orientations.

the 30° rotation around each of these can be carried out in two directions; there are, therefore, eight crystallographically equivalent orientations of the type required by maximum boundary mobility. Out of these, in most cases of recrystallization or coarsening, only one or two actually are observed to occur. The question is then whether it is possible to explain this discrepancy in terms of the oriented growth theory. Let *a*, *b*, and *c* in Fig. 2a represent schematically three of the crystallographically equivalent orientations with high boundary mobility. If the orientation distribution of nuclei is fairly uniform (line I), all three orientations may be expected to occur in the recrystallization texture. An asymetrical nucleus distribution (line II), which in itself would not give rise to a well-defined texture in the sense of oriented nucleation (compare with Fig. 1b), might nevertheless give the desired selection from among the eight crystallographically equivalent orientations of high boundary mobility. Another possible answer to the above question is that the orientations *a*, *b*, and *c* strictly speaking are not crystallographically equivalent, since a deformation texture or a recrystallization texture, no matter how sharply developed, does not possess the symmetry of a corresponding ideal single crystal. Thus, the mobility maxima at *a*, *b*, and *c* may have quite different values, favoring certain ones among the "equivalent" orientations, Fig. 2b, regardless of nucleus distribution.

It was observed by Burgers and Basart[8] that the recrystallized grains growing in a slightly deformed single crystal of aluminum, in contrast to those formed after heavy deformations, do not exhibit a well-developed texture. The question arises how this behavior can be reconciled with oriented growth. It has been pointed out[5] that the large scatter of orientations in this case may be a result of scarcity of nuclei in all of the orientations favored by high boundary mobility, see line III in Fig. 2a. It is indeed quite probable that an annealing texture does not develop here, because the lack of suitable nuclei prevents oriented growth from becoming operative. This state of affairs in no way affects the general conclusion that annealing textures, when they do occur, are the result of oriented growth.

What is the physical basis for the orientation dependence of boundary mobility? In a previous publication[5] the hypothesis was advanced that the mobility of a grain boundary depends on the rate of self-diffusion along this boundary. Furthermore, it was shown that at least qualitatively the correct orientation dependence of boundary mobility results from this hypothesis, if a plausible assumption is made concerning the rate of grain boundary self-diffusion as a function of the relative orientation of the grains meeting at the boundary. It was assumed that the rate of grain boundary self-diffusion decreases with decreasing grain boundary surface energy, because the atoms at the boundary are more tightly held in their positions. According to this assumption grain boundary self-diffusion is very slow at boundaries where the two grains have nearly the same orientation, and at coherent twin boundaries. This has been experimentally confirmed for tin by Fensham.[9] Analogous results were reported more recently by R. S. Barnes for the grain boundary diffusion of copper in nickel.[10] The above hypothesis, associating grain boundary mobility with the rate self-diffusion along the boundary, also received some independent confirmation recently. D. Turnbull[11] found that the free energy of activation for grain boundary migration in the coarsening of silver is nearly the same as the free energy of activation for grain boundary self-diffusion in the same material. It is quite likely that the elementary processes involved in atomic movements necessary for grain boundary migration are the same as those involved in grain boundary self-diffusion.

Acknowledgment

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Kinetics of Precipitation in Supercooled Solid Solutions

by G. Borelius

ABOUT the turn of the century, Gibbs' thermodynamic theory of heterogeneous equilibrium, on the one hand, and the experimental methods of thermal and microscopic analysis, on the other, gave to the physical metallurgist his first scientific tool, the equilibrium diagram. The classical equilibrium diagram of a binary alloy system shows the boundaries between ranges of homogeneous and heterogeneous equilibrium in their dependence of concentration and temperature. A homogeneous solid solution which on cooling passes such a boundary is assumed to precipitate, forming a mixture of two phases with different concentrations.

The equilibrium diagram and the equilibrium theory, however, give no information about the time scheme of the process or the intermediate states passed during precipitation. For this reason it satisfies neither the practical need of the metallurgist nor the curiosity of the physicist. As a matter of fact, in the heat treatment of alloys for technical use the objective very seldom is the equilibrium state. Thus good mechanical properties of construction material are connected, for the most part, with some intermediate state. As these intermediate states are thermodynamically unstable, there is, from a theoretical point of view, always to be expected a decay of the good properties with time; and it is a matter also of practical interest to know whether this natural life time of a material is of the order of, say, ten or thousands of years. Thus, for many reasons, there is a current demand to complete our knowledge of equilibrium through knowledge of the kinetics of the precipitation phenomena. From the point of view of the physicist, the most interesting question in this case is whether there are any general laws governing the kinetics.

According to a generally accepted view, precipitation is ruled by two more or less independent phenomena, the formation of nuclei of a new phase and the growth of these nuclei. It is also commonly accepted that there is a tendency for the velocity of growth to increase with increasing temperature because of the increasing mobility of the atoms. There is also a tendency for the velocity of growth to decrease in the neighborhood of the two-phase boundaries. So far, however, very little is known quantitatively about this fundamental phenomenon in the case of solid metallic systems. In our laboratory attention has been directed especially toward the nucleation phenomena, and a series of measurements have been carried out with the guidance of a working hypothesis (based on experiences from previous work on order-disorder transformations in alloys) about the influence on the nucleation of thermodynamic potential barriers. However, before discussing the experiments, the theoretical ideas will be considered.

In a binary solid solution the arrangement of atoms on the lattice points approaches with increasing temperature a state of full randomness, as illustrated by the ball model of Fig. 1, that might represent a [111] plane of a face-centered alloy with 30 pct "black" and 70 pct "white" atoms. In reality the atoms are changing places continually with their neighbors so that the picture should rightly have been a moving one. On account of this thermal motion the concentration of black atoms within a certain group of, say, a hundred or a thousand lattice points fluctuates with time around the bulk concentration of 30 pct in a manner governed by statistical laws. With decreasing temperature two independent changes in this state grow more and more important. First, the mobility of the atoms decreases, and second, the forces between the atoms will have an increased influence on the fluctuations. In alloys with a tendency for precipitation, which are the concern of this lecture, the distribution function of concentration fluctuations will broaden, so that the relative probability of great local variations from the bulk concentration increases.

Fig. 2 gives an example of such a fluctuation. When the alloy is supercooled below the solubility limit into the range of two-phase equilibrium, the fluctuations will now and then at some point give rise to a state that resembles the equilibrium state and thus will form a stable nucleus that is capable of growing by diffusion processes. In discussions with colleagues and in the literature, I have often encountered the idea that three or four atoms of the dissolved metal could form a nucleus of the new phase. A look at the ball model might be enough to indicate that this cannot be true. If it were true, there should be nothing but nuclei, whereas we know from experiment that nucleation must be a rather rare occurrence. In fact we have, as will be mentioned later, certain reasons to believe that the nuclei are formed by fluctuations containing some hundreds of atoms, which should be the order of the number of black balls in the fluctuating group of the figure, if it were extended into three dimensions.

As a working hypothesis we have assumed that the fluctuations producing nuclei, though large and rare, still are ruled by the distribution laws of fluctuations of the supercooled solid solution in its initial state. Thus the probability of nucleation will be connected to the thermodynamic properties of the solid

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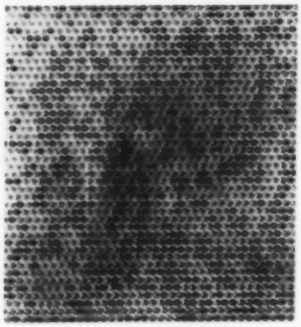
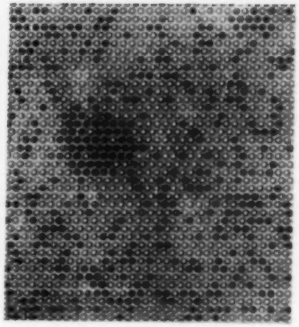


Fig. 1 (left)—Ball model of a 30 pct solid solution with random distribution of atoms.

Fig. 2 (right)—Ball model of a big concentration fluctuation in a solid solution.



solution itself. These properties in turn may be determined approximately from the equilibrium diagram, and it is possible to obtain a connection between the equilibrium diagram and the nucleation that might be examined experimentally.

Fig. 3 gives an outline of the theoretical relationships. The upper figure is the equilibrium diagram of a solid binary system such as Au-Pt or Au-Ni with a gap of solubility. The solid line is the limit of solubility. In the lower diagram, the curve F shows the free energy as a function of the concentration at a certain temperature T. Between the two contact points of the double tangent, the curve itself gives the free energy of the unstable, supercooled homogeneous solutions, whereas the tangent gives the free energy of the stable mixture of two phases. The part of the free energy that is of importance here may be written approximately:

$$F = U - TS \qquad [1]$$

where U and S, the structural part of the energy and the entropy, are functions of the concentration x only, but not of the temperature T. The entropy is given approximately by:

$$S = R\,[x \ln x + (1 - x) \ln (1 - x)] \qquad [2]$$

whereas U has to be determined analytically or graphically, so that the contact points of the double tangent at all temperatures fit to the empirical solubility limits.

The theory of fluctuations shows that the distribution of fluctuations is highly dependent on the second derivative of the free energy with respect to concentration, that is, on the curvature of the F-x curve. If this curve bends upward, as it does on both sides within the gap of solubility, the free energy is increased locally by a fluctuation, and as the free energy always tends to a minimum, the fluctuations are repressed, the more the curve is bent. If the curve bends downward, as it does in the central part of the gap, the fluctuations are unrepressed and their distribution is undetermined. A retardation of the fluctuations and accordingly of nucleation therefore might be expected to start above a line, dashed in the phase diagram of Fig. 3, which is the locus of the inflection points of the isothermal F-x curves. Van der Waals, who in the nineties pointed out this line as the lower limit of metastable equilibrium, called it the spinodal, a name that we will adopt in the following. Above this line the formation of a nucleus presupposes that a group of, say, n atoms passes a thermodynamic potential barrier, which under certain simplifying assumptions can be expected to be the maximum difference ΔF between the F-x curve and the tangent to the curve at a point corresponding to the concentration of the alloy concerned. The probability of nucleation might be given by the formula:

$$P = P_0 e^{-\frac{Q}{RT}} e^{-\frac{n\Delta F}{RT}} \qquad [3]$$

where Q is the activation energy per mol for the change of place of the atoms. As to the number n, the theory so far cannot give any prediction either of its magnitude or its dependence on concentration or temperature; it has to be determined from experiment.

The growing nuclei will give rise to new types of

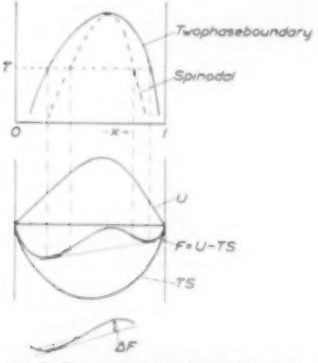


Fig. 3—Thermodynamic relations for a system with limited solubility.

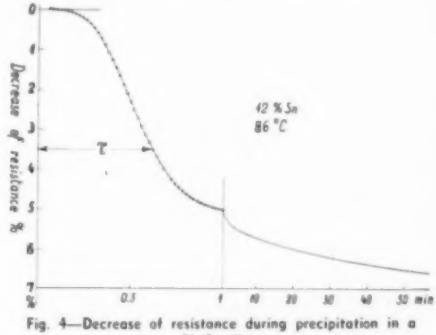


Fig. 4—Decrease of resistance during precipitation in a Pb-Sn alloy.

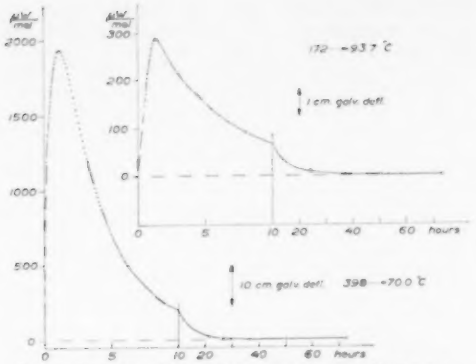


Fig. 5—Evolution of heat during precipitation of nitrogen from solid solution in alpha iron.

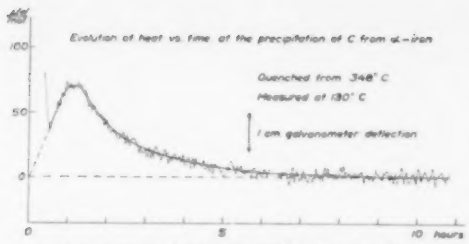

Evolution of heat vs. time at the precipitation of C from α-iron
Quenched from 348° C
Measured at 130° C
1 cm galvanometer deflection
hours

Fig. 6—Evolution of heat during precipitation of carbon from solid solution in alpha iron.

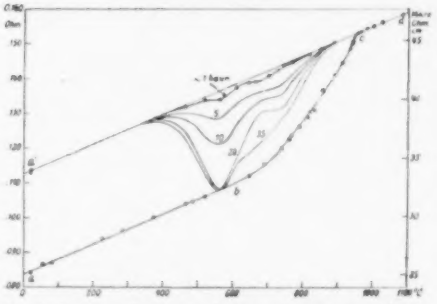


Fig. 7—Decrease of resistance during precipitation in an Au-Pt alloy with 30 pct Pt.

forces in the lattice and corresponding new types of potential energy. Frenkel, Becker, and others have made calculations on the basis of a special surface energy at the surface of the nucleus, and Gorsky, Mott, Nabarro, and others on the basis of internal strain caused by the different atomic distances in and outside the nucleus. In certain cases these strains probably will stop the growth of the nucleus at a submicroscopic size, which at least for the present seems to be a natural interpretation of the submicroscopic age-hardening phenomena. In other cases the nuclei break away from the lattice of the matrix and then are capable of growing by diffusion into crystals of microscopic or macroscopic sizes.

For a given alloy the precipitation is dependent on two variables, temperature and time. As always when examining a phenomenon which is a function of two variables, it is convenient, if possible, to study these variables separately. In the present case the obvious procedure is to try to supercool the alloy from a temperature where it is homogeneous to a temperature within the gap of solubility rapidly enough to maintain its homogeneity, after which the precipitation has to be studied at constant temperature. For such isothermal investigations modern physical metallurgy has at its disposal a variety of experimental methods which may be divided into two main groups. In one group are the methods that necessitate the interruption of the heat treatment at the constant higher temperature in order that the measurements can be performed at or near room temperature. This is the case in the use of the microscope, electron microscope, X-ray cameras, hardness testing, damping methods, etc. The other group comprises methods which allow continuous measurements at the temperature of precipitation itself, such as measurements of resistance, magnetic susceptibility, changes of volume, and changes of internal energy, the latter studied by the heat given off from the specimen. In our laboratory two methods have been employed for the most part: Resistometric measurements which are easy and often very useful, especially for the first orientation; and calorimetric measurements, which are less simple to perform, but give results that are more directly interpretable.

We shall not discuss here the experimental details but only give examples of the type of results that are obtained with the methods used. Fig. 4 shows the relative decrease of resistivity during precipitation of a supercooled Pb-Sn alloy. In this case the precipitation is rather rapid and a special photographic method of registration was used. As a relative measure of the time of precipitation we have used, for instance, the half-value time τ, or the time for a decrease of resistivity by 1 or 2 pct, or the reciprocal of the decrease of resistance during a certain time, or some similar measure.

Fig. 5 shows curves for the evolution of heat dur-

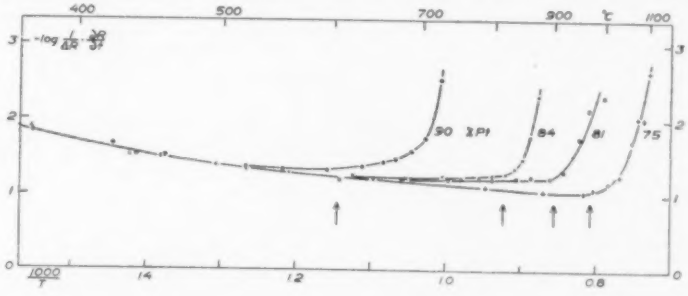


Fig. 8—Determination of limits of retardation by resistance measurements on Au-Pt alloys.

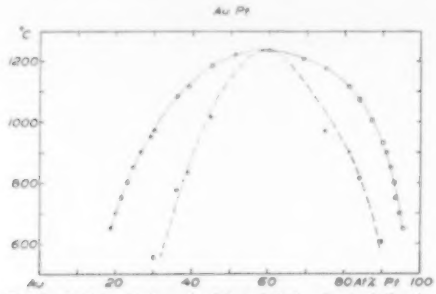


Fig. 9—Solubility limits, spinodal, and limits of retardation in the system Au-Pt.

ing the precipitation of nitrogen dissolved in α iron. The heat of precipitation is rather small. If after the quenching from 172° to 94°C, the specimen had been insulated thermally, the total increase of temperature caused by the heat of transformation, evolving during some 50 hr, would have been 0.2°C.

Fig. 6 gives an idea of the present limits of the experimental possibilities of the calorimetric method. It describes evolution of heat during the precipitation of carbon from α iron, ferrite. The specimen had been heated for some time at 348°C, where the solubility of carbon in the ferrite is about 2/10,000 of a percent by weight, and after quenching it was aged at 130°C. This temperature was chosen so that precipitation would be completed in the course of one day, which was the most convenient rate. In this case the specimen, if insulated during the precipitation, would have obtained an increase of temperature of only about 0.02°.

For these investigations we chose those systems of alloys that are simple and of greatest interest; namely the systems Au-Pt and Au-Ni, which are the only known systems with full mutual solubility at high temperatures, and a gap of solubility at lower temperatures; the system Pb-Sn with a maximum solubility of 30 atomic pct Sn and a precipitation of nearly pure Sn; the system Al-Zn with a broadest range of solubility from 0 to 65 atomic pct Zn, also covering a eutectoid concentration; and the system Al-Cu which, being of great technical importance, has been investigated in many laboratories, so that our results could be compared with those of other investigators. We have also done some calorimetric work on the precipitation of nitrogen and carbon dissolved in α iron.

The first system investigated in search of influences of thermodynamic potential barriers was the Au-Pt alloys. Results of resistivity measurements by Johansson and Hagsten on an alloy with 30 atomic pct Pt are shown in Fig. 7. Alloys which were cooled rapidly from above the two-phase range gave resistances on a nearly straight line in the resistance-temperature diagram. Further the figure shows the resistances after 1, 5, 10, 20, and 35 hr and after reaching equilibrium. Up to about 550°C the velocity of precipitation increases with the temperature owing to increased mobility of the atoms. Here, 400° below the solubility limit, a retardation sets in which, some 100° below the limit, is so strong that there is no appreciable change in resistance even after 35 hr, although the motion of the atoms must be expected to be very lively at this temperature.

Wictorin has investigated a number of Au-Pt alloys in the same way. Plotting the logarithm of the reciprocal of the relative decrease of resistance in 10 min against the reciprocal of the absolute temperature, he obtained curves as shown in Fig. 8 with rather well defined lower limits of retardation.

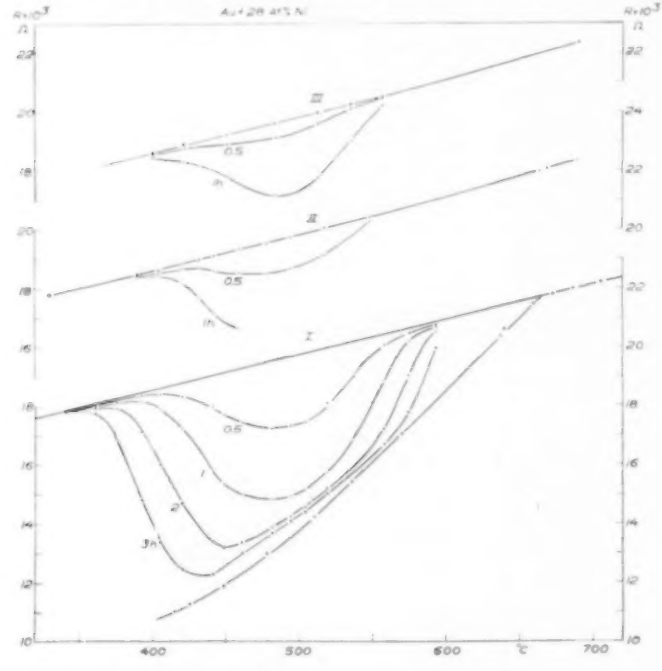


Fig. 10—Decrease of resistance in an Au-Ni alloy with 28 atomic pct Ni during precipitation.

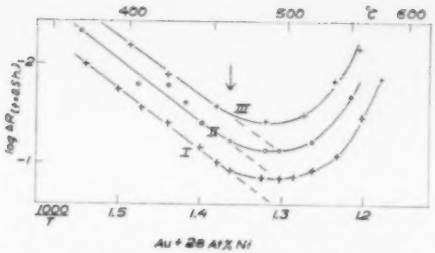


Fig. 11 (above)—Dependence on temperature of the rate of precipitation in an Au-Ni alloy with 28 atomic pct Ni.

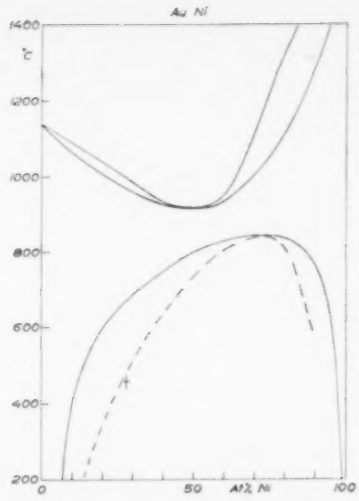


Fig. 12 (right)—Solubility limit, spinodal, and limit of retardation in the system Au-Ni.

A careful redetermination of the two-phase boundary, the solid line in Fig. 9, made it possible to calculate the free energy and the spinodal, the dashed line. Within the limits of experimental uncertainty the limits of retardation coincide with the spinodal.

In the system Au-Ni, we have investigated quite thoroughly only one single alloy with 28 atomic pct Ni. A first series of measurements, going from higher to lower temperatures, gave the resistance temperature diagram I of Fig. 10, that was completed by the measurements of the equilibrium state from lower to higher temperatures. A later series, II, showed slower precipitation and a still later one, III, even lower velocity of precipitation. A plot of the logarithm of the reciprocal of the decrease of resistance during the first 30 min against the reciprocal of the absolute temperature, which gives a clearer view of the initial stage of precipitation, is shown in Fig. 11. The three rather parallel logarithmic curves can be interpreted as a sum of the logarithm of a factor decreasing with the increasing mobility of the atoms with increasing temperature, which gives the straight line in the diagram, and the logarithm of a retarding factor. The fact that the curves are parallel to each other in the logarithmic diagram seems to indicate that there are variations in the a priori probability of nucleation between the three states. In fact a microscopic investigation showed that, at an intermediate stage of the precipitation process, the number of centers of the second phase was very different in different crystal grains. On the other hand, the lower limits of retardation, which appear rather sharply, are the same, about 460°C, in all three cases. Fig. 12 shows how this limit coincides with the position of the spinodal which was calculated from measurements of the solubility limit by Köster and others.

The system Pb-Sn has been studied with resistivity and calorimetric measurements. Fig. 13 shows the logarithm of the time for a decrease in resistance of 2 pct vs. the reciprocal of the absolute temperature for five concentrations. The probable positions of the lower limits of retardation are marked by arrows.

Fig. 14 shows the phase diagram with the experimental limits of retardation marked by crosses. The oblique cross is obtained from a calorimetric investigation. The upper dotted line is the spinodal

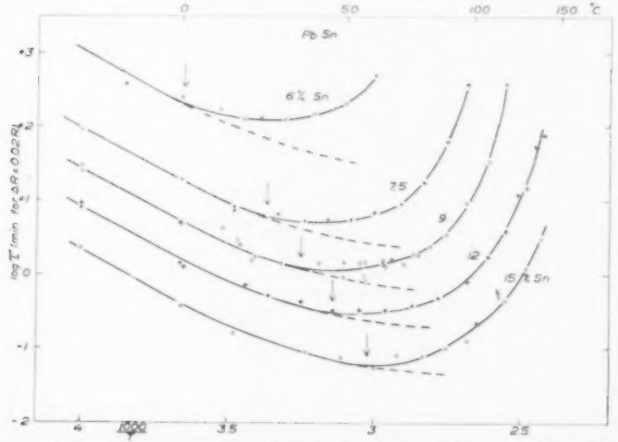


Fig. 13—Logarithms of times for a decrease of resistance of 2 pct vs. reciprocal of absolute temperature for Pb-Sn alloys.

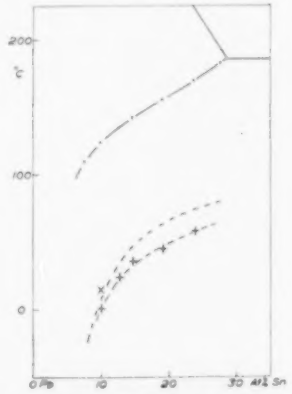


Fig. 14—Limit and solubility, calculated spinodal, and limits of retarded precipitation in the system Pb-Sn.

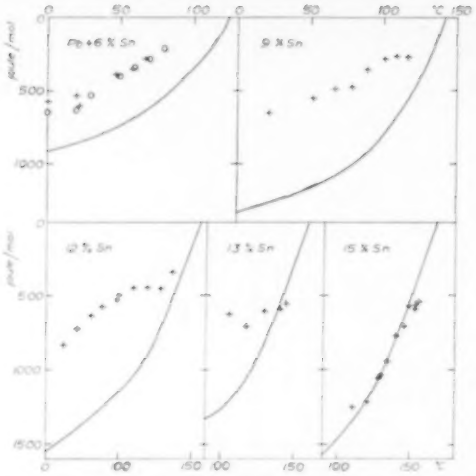


Fig. 15 (left)—Calculated and observed total heat of precipitation in Pb-Sn alloys.

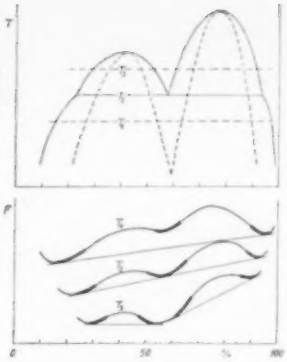


Fig. 16 (right)—Thermodynamic relations for a system with a eutectoid point.

calculated from the carefully redetermined two-phase boundary. As the available boundary line in this system is rather short, the calculation may be somewhat uncertain.

Calorimetric investigations also have given another type of information. Precipitation above about 100°C has, as shown in Fig. 15, given the total decrease of internal energy that could be expected from the phase diagram, whereas precipitation below 100°C has given only about half of the calculated decrease. There seems to exist below 100° some intermediate, metastable state, the nature of which we have not discovered so far.

The three systems under discussion have a simple gap of solubility between two primary solid solutions. It was of special interest to try to test the working hypothesis also on a system with a eutectoid point. An imaginable system of this kind with full solubility at high temperatures is shown in Fig. 16, together with free energy curves for the eutectoid temperature T_2, a higher temperature T_3, and a lower one T_1, the parts of these curves for the supercooled solid solutions having a positive second derivative of the free energy are marked with thick lines. The locus of the inflection points, the spinodal, is the dashed line in the upper part of the figure. Although at the lower temperature T_1 there is only one continuous gap of solubility, there are three ranges with positive second derivatives, one of them in the central part of the gap.

Unfortunately there is no known system of this type with an unbroken series of solid solutions at high temperatures. In the system Al-Zn, however, there is at least an unbroken solubility from pure Al to a bit on the other side of the eutectic concentration. In Fig. 17 the solid lines show the two-phase boundaries according to resistometric measurements by Fink and Willey completed by more detailed measurements of our own. The dashed line is the spinodal determined by graphical methods, in this case with some difficulty and uncertainty. The crosses are empirical lower limits of retardation determined by resistivity measurements, and the circles such limits determined by calorimetric investigations. The good agreement with the calculated spinodal may partly depend on good luck, as the results are in fact somewhat complicated.

In this system Guinier has observed at low temperatures a submicroscopic precipitation of the

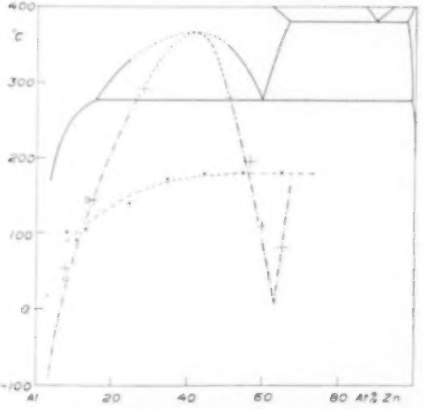
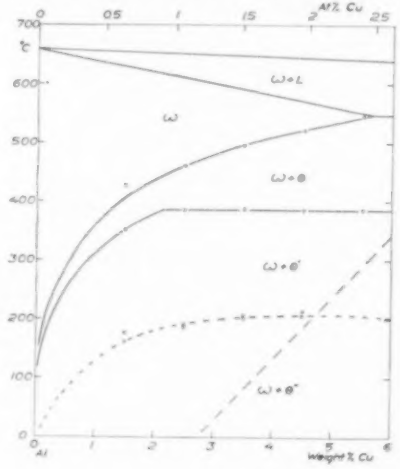


Fig. 17 (above)—Solubility limits, calculated spinodal, lower limits of retarded precipitation, and supposed upper limit of the Guinier-Preston aggregates in the system Al-Zn.

Fig. 18 (right)—Phase limits and calculated spinodal in the system Al-Cu.



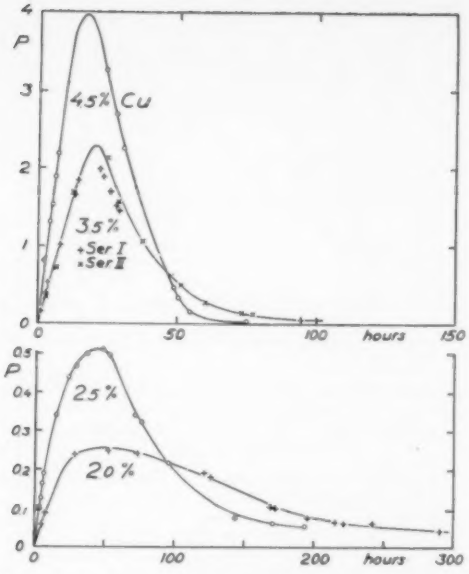


Fig. 19 (left)—Evolution of heat during precipitation in Al-Cu alloys at 225°C.

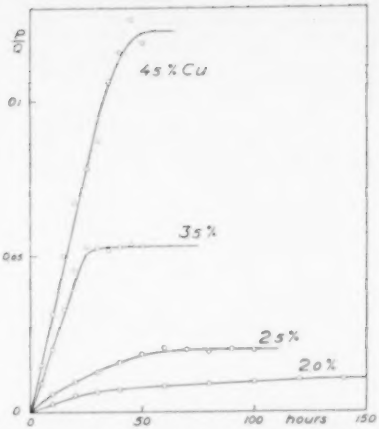


Fig. 20 (above)—Ratio of power P to heat Q still to be given off as a function of time in Al-Cu alloys at 225°C.

Guinier-Preston type. Unpublished results of thermal analysis from our laboratory have shown that homogeneous Al-Zn alloys, which are cooled rapidly and aged at low temperatures when heated at a rate of the order of 1° per min at higher temperatures, show an absorption of heat that was found to start rather sharply at the temperatures marked by oblique crosses in Fig. 17. It is most probable that the line drawn through these points in the diagram is the upper limit of the range of existence of the Guinier-Preston aggregates. It is of particular interest to observe that the retardation of the initial rate of precipitation, governed by the position of the spinodal, appears, as well, within and above this range. From our point of view this is understandable as fluctuations are supposed to be necessary for nucleation in all forms of precipitation.

Another system from which there are kinetic studies of precision to present is the system Al-Cu. The constitution diagram for the Al-side of the system is shown in Fig. 18. Al dissolves up to 5.5 wt pct Cu at 550°C. There are three known precipitates θ, θ', and θ''. θ has the composition Al_2Cu and is the stable precipitate at all temperatures below the two-phase boundary. θ' is another, metastable, form of Al_2Cu appearing as an intermediate stage of the transformation below about 385°C. θ'' is a submicroscopic intermediate precipitate appearing below about 200°C and causing the well-known age hardening of the Al-Cu alloys. Its nature has been discussed on the basis of X-ray investigations on single crystals by Preston, Guinier, Jagodzinski and Laves, and others. The upper limits of the three states, as shown in the figure, were determined by thermal analysis at rising temperature. The spinodal, as calculated from the two-phase boundary, is represented by the dashed line down to the right in the figure.

In contrast to the alloy systems already reported, we have for the Al-Cu alloys no measurements to report for constant concentrations at varying temperatures crossing the spinodal. They would probably be rather difficult to perform in this range because of the rapid precipitation. But an attempt has been made to study the influence of the thermodynamic potential barriers on alloys with varying concentrations at three constant temperatures, 225°, 110°, and 20°C. The measurements are made by the calorimetric method which is, in this special case, preferable to resistance measurements, the results of which are complicated and difficult to interpret.

At 225°C, we have studied the precipitation of the θ' phase in the range of retarded nucleation. The calorimetric power-time curves are shown in Fig. 19. They are of a simple form making it possible to follow the precipitation process from the beginning to the end. The total amounts of heat obtained by integration are, within the limits of the experimental uncertainty, in accordance with the values calculated from the phase boundaries.

For a discussion of the formation of the nuclei, it is convenient to consider, instead of the power P

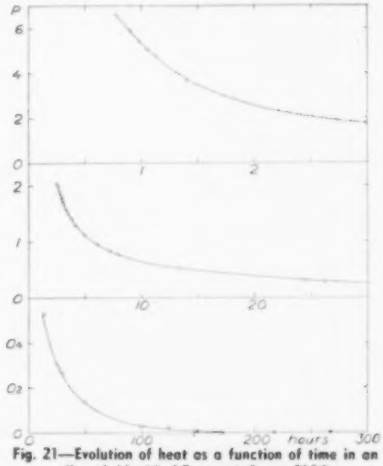
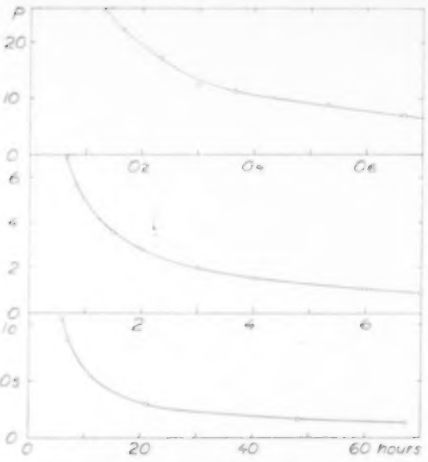


Fig. 21—Evolution of heat as a function of time in an alloy of Al with 4.5 wt pct Cu at 20°C.



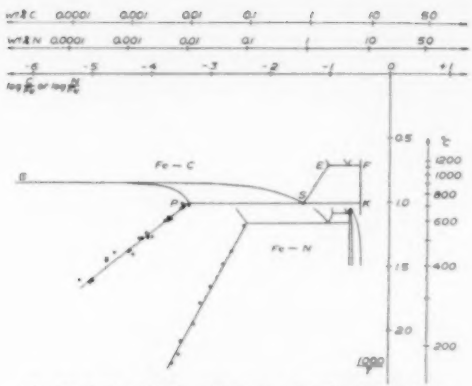


Fig. 22 (left)—Evolution of heat as a function of time in an alloy of Al with 4.5 wt pct Cu at 100°C.

Fig. 23 (above)—Solubility limits in the logarithmic phase diagrams FeN and FeC.

itself, the quantity P/Q, where Q is the heat still to be given off. P/Q, which may also be written dQ/Qdt, is aproximately proportional to the fraction of the atoms still in solution, which per unit of time go over to the precipitate and can be shown to be proportional to the number of nuclei per unit of mass. Fig. 20 gives P/Q as a function of time. It shows that the number of nuclei first increases linearly and then reaches a constant value. The initial slopes of the curves are relative measures of the probability of nucleation in the supercooled solutions and are, according to eq 3, related to the product $n\Delta F$ of the number n of atoms necessary to form a stable nucleus and the thermodynamic potential barrier ΔF which can be calculated. In fact we have found good agreement with theory for $n = 120$.

The precipitation at 20°C, which is known to give the submicroscopic Guinier-Preston aggregates and which has been studied on samples with concentrations in a range below or near the spinodal, where nucleation is unretarded, give quite another picture in the calorimetric power-time diagram. Because of the unretarded fluctuations and the small distances of diffusion, the first precipitation is so rapid that the concentration of Cu still in solution, which was 4.5 pct in the case of Fig. 21, had decreased to about 2 wt pct before the specimens after quenching had reached the steady state necessary for measurement. What was observed during the measuring series is dependent on the further formation of nuclei, which is more and more retarded as the concentration of the solution decreases and the thermodynamic potential barrier increases. As can be expected under such circumstances, the power-time diagrams, of which Fig. 21 gives an example, take on a hyperbolic form and are not very much different for the various alloys investigated which held from 2.5 to 5.5 wt pct Cu.

The aging at 100°C gives, as is also known from other investigations, a precipitation of the θ' as well as the θ'' phase. The power-time curves, exemplified by Fig. 22, are first hyperbolic like the curves for 20°C but end with an exponential part like the curves at 225°C.

The calorimetric investigations on the precipitation of nitrogen and carbon from solutions of α iron, of which three examples were given in Figs. 4 and 5, are so far very incomplete concerning the kinetics of the phenomena. However, the measurements give a new determination of the solubility limits, which is independent of all chemical determinations of the solubility and which might be of some interest of its own.

In the case of nitrogen the evolution of heat was observed at 80° and 94°C in samples which were heated previously at various temperatures from 170° to 575°C in order to obtain equilibrium of solution and thereupon quenched to room temperature. In the case of carbon the measurements were made at 100° or 130°C and covered a range of equilibrium of solution from 350° to 700°C. From the experimental values of the total amount of heat determined at various temperatures, the solubilities may be calculated by means of simple thermodynamic relationships on the assumption that the heat of solubility is constant through the whole range of temperatures covered by our experiments; the accuracy of this assumption, however, for the present is difficult to estimate.

Fig. 23 shows the results on the phase diagrams of Fe-N and Fe-C. Instead of the usual diagrams, with concentration and temperature along the axis, a diagram is used with the logarithms of the atomic ratios N:Fe or C:Fe vs. the reciprocal of the absolute temperature. The advantage of this type of diagram is that the solubility limits for small concentrations approach straight lines.

The results obtained so far seem to indicate that there are besides the phase boundaries two things which have a marked influence on the precipitation and which are fundamental enough to make a part of the phase diagram, namely the spinodal and, at least in some cases, the upper limits of the ranges of existence of various metastable states, as for instance the Guinier-Preston aggregates. It has to be emphasized, however, that the attacks on the problem of understanding the kinetics of precipitation phenomena are still rather fumbling. So, in order to obtain a first simple outlook, we have passed by some important complicating factors, such as the special influences of grain boundaries and cold working and the decreasing rate of crystal growth with decreasing supercooling. Further, our calculations of the free energy from the phase boundaries are only a first rather rough approximation.

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aime NEWS

Quality and Inspection Techniques Stressed at New England IMD Meeting

The fifth annual New England Regional Conference of the Institute of Metals Division, AIME, was held at the Hotel Taft, New Haven, Conn., April 13 and 14. On Friday morning, April 13, Geometric Tool Co., Div. of Greenfield Tap & Die Corp., and the Greist Mfg. Co., held "open-house" for the 155 conference delegates. In addition, Hammond Laboratory of Yale University was toured by a number of the delegates.

Friday afternoon, Arthur W. Young, Bridgeport Brass Co., Bridgeport, presented a paper on "Spectrographic Control Testing in the Brass Mill"; a paper prepared by C. K. Stewart, International Nickel Co., N. Y. on "Embrittling Factors in Heat Treated Steels" was read; and A. S. Burgoyne, Pratt & Whitney Div., Niles-Bement-Pond Corp., West Hartford, spoke on "New Gaging Techniques for Metal Rolling Operations."

Dr. Bruce Old, vice-president, Arthur D. Little, Inc., Cambridge, Mass., was toastmaster for the banquet, which 92 persons attended on Friday evening. A. N. Winchell was presented with the AIME Legion of Honor Pin in recognition of his 50th year as a member of AIME.

Speakers for the evening were Tom Lyon, director of Supply Div., Defense Materials Administration, and Rear Admiral R. M. Watt, Assistant Chief and Director, Production Policy Div., Office of Naval Materials, Dept. of the Navy. Admiral Watt outlined the present shortages of strategic materials, stressing the necessity of keeping sea lanes open for importing the many materials not available domestically. Mr. Lyons took the domestic side of the materials program, pointing out that the United States' mineral industry, although a basic one, was small and would have to be increased rapidly to keep up with the material demand. Substitutes for many materials will have to be developed.

The last conference session, a technical session, was held Saturday morning. Papers were presented on "Phase Contrast Metallography," by George L. Kehl of Columbia University; "Electron Metallography," by R. D. Heidenreich of Bell Telephone Research Laboratories; and "Recent Developments in X-Ray Methods for Texture Determination," by Dr. Paul Beck of Notre Dame University.

John A. Swift, Swift Industrial Chemical Co., was chairman for the Conference; Albert I. Blank, Chase Brass & Copper Co., was vice-chairman; Dr. Michael B. Bever, Massachusetts Institute of Technology, was secretary, and Dr. George P. Swift, treasurer. At a meeting following the close of the conference, Albert I. Blank was elected chairman for the Sixth Annual Conference to be held in Boston in 1952; with James H. Moore, National Research Corp., vice-chairman; Winston H. Sharp, Pratt & Whitney Aircraft, secretary; and L. P. Tarasov, Norton Co., treasurer.

Engineering Manpower Report Issued

The Engineering Manpower Commission of Engineers Joint Council has issued its first report on "Utilizing Engineering Manpower." Issued as EMC Bulletin #1, the report discusses procedures for requesting necessary occupational deferments and delays for personnel. Included is a statement on the problems of both Government and industry in selecting and utilizing its technical personnel.

Bulletin #1 is available from Engineering Manpower Commission, 29 West 39 St., New York 18 for 25c a copy. AIME members on the EMC are Edward H. Robie; George B. Corless, Standard Oil Co. (N.J.); Max W. Lightner, Carnegie-Illinois Steel Corp.; and Harry J. O'Carroll, Kennecott Copper Corp.

B. C. Snell Joins Advertising Staff

Byron C. Snell joined the advertising staff of MINING ENGINEERING and the JOURNAL OF METALS on May 1. He will work with James A. Stangarone, who henceforth will sell space in both publications rather than in the JOURNAL OF METALS alone. Mr. Snell will make his headquarters in Pittsburgh and Mr. Stangarone in New York.

Mr. Snell graduated from Ohio State University in 1933. For the past nine years he has been regional business manager for the Penton Publishing Co., covering the territory tributary to Pittsburgh for *Steel* magazine.

The new arrangement follows the resignation of Wheeler Spackman as advertising manager of MINING ENGINEERING and its predecessor, MINING AND METALLURGY.

Messrs. Snell and Stangarone will cover the East and Middle West, McDonald-Thompson continuing to act as publisher's representatives in the Pacific Coast States for MINING ENGINEERING and for the JOURNAL OF PETROLEUM TECHNOLOGY in the oil areas west of the Mississippi.

AIME To Release Three Books

Three special volumes to be published within the next year or two by the AIME under the sponsorship of the Seeley W. Mudd Memorial Fund and the Henry L. Doherty Memorial Fund have been authorized. The first of these, now in galley form, will be the second edition of *"Basic Open Hearth Steelmaking,"* which should be available within a few months. The second to appear will undoubtedly be *"Petroleum Conservation,"* edited by Stuart E. Buckley, the manuscript of which is completed. This is sponsored by the Doherty Fund. Third is a new edition of *"The Marketing of Metals and Minerals,"* a book first published a quarter century ago which has long been out of print. F. E. Wormser, one of the original authors and now vice-president of the St. Joseph Lead Co., and Simon D. Strauss, vice-president of the American Smelting & Refining Co., will collaborate on the new edition. Authorization to proceed with the work was voted at the meeting of the Board of Directors on Apr. 18.

1951 AIME Budget Shows Surplus

At the April meeting of the Board of Directors the final budget for the current year, showing a surplus of $6430, was adopted. Total income is expected to be $502,700, compared with $493,689 in 1950; expenses, $496,270, compared with $511,411 in 1950. The budget is believed to be conservative, based on present costs. Details of the overall budget, as well as the breakdown by Branches, are shown in the accompanying table.

PROPOSED BUDGET FOR 1951

	FINAL BUDGET 1951	1951 MINING	1951 METALS	1951 PETROLEUM
INCOME				
Dues:				
Current	$272,000	$142,038	$66,204	$63,758
Arrears	4,500	2,327	1,111	1,062
New	25,000	10,000	6,250	8,750
Initiation	17,000	6,800	4,250	5,950
Total	$318,500	$161,165	$77,815	$79,520
Publications:				
Advertising	$135,000	$63,000	$45,000	$27,000
Journal Sales	17,000	6,000	7,000	4,000
Transactions Sales	20,000	7,300	6,400	6,300
Other Sales	4,000	1,500	972	1,528
Total	$176,000	$77,800	$59,372	$38,828
Other income:				
Interest	$5,200	$2,600	$1,200	$1,400
Miscellaneous	3,000	1,566	730	704
Total	$8,200	$4,166	$1,930	$2,104
TOTAL INCOME	$502,700	$243,131	$139,117	$120,452
EXPENSES				
Membership and Sections:				
Sections, traveling, etc.	$15,000	$8,000	$3,800	$3,200
Divisions and Branches	56,000	24,823	13,377	17,800
Meetings	1,000	522	243	234
Library Assessment	6,500	3,394	1,582	1,523
Building Rental	13,000	6,770	3,180	3,052
Secretary Travel	2,500	1,306	608	586
Total	$94,000	$44,815	$22,790	$26,395
Publications:				
Journals	$252,500	$112,500	$92,000	$48,000
Transactions	26,000	9,250	10,110	6,640
Directory (Comm. list)	2,000	1,000	520	480
Other	10,000	—	—	*10,000
Total	$290,500	$122,750	$102,630	$65,120
General and Administrative:				
Salaries, other	$49,000	$25,531	$11,976	$11,502
Accounting and salaries	25,000	13,121	6,035	5,853
Membership and salaries	21,000	10,921	5,144	4,933
Pensions and annuities	7,000	3,788	1,604	1,607
Insurance	1,000	522	243	234
Furniture and fixtures	2,000	1,044	486	468
Miscellaneous	4,000	2,088	973	937
Social Security Tax	2,160	1,127	525	508
N.Y. State Disability	610	318	148	144
Total	$111,770	$58,450	$27,134	$26,186
TOTAL EXPENSES	$496,270	$226,015	$152,554	$117,701
UNEXPENDED INCOME	$6,430	$17,116	($13,437)	$2,751
Appropriation Income Rocky Mt. Fund (Mining Secretary) contingent	12,000			
Unexpended balance including appropriation	$18,430			

* Petroleum Statistics Volume.

Last year the Metals Branch had a deficit of close to $42,000, its expense for publications being over $119,000. This has been cut down in the 1951 budget to $102,630 for publications, the Branch deficit being reduced to $13,437. This promises to be the last year that the Metals Branch will suffer a deficit. Advertising income in the JOURNAL OF METALS is showing a healthy increase, justifying the money that was put into the journal to get it established. Its net advertising income in 1949 was $11,000; in 1950 $30,000; with $45,000 budgeted in 1951.

The Mining Branch expense for 1951 includes for the first time an appropriation for the Western Secretary and the expenses of his office, amounting to $12,000. If there should be a deficit for the year, the Rocky Mountain Club Fund has promised to meet it up to this $12,000 figure, thus adding an extra factor of safety to the budget.

For the first four months of 1951, AIME income was $336,610, or $27,428 in excess of the same period in 1950. Expenses were $184,642 or $14,721 less than in the same period last year. Thus the Institute completes the one-third of the year with an improvement over its financial position of a year ago by $42,149.

AIME Authorizes Five Awards

AIME Board of Directors has authorized granting five awards at the annual meeting in 1952. The name of the award, the purpose for which granted, and the name of the chairman of the committee appointed to select the recipient are as follows:

Charles F. Rand Medal for distinguished achievement in mining administration, the term mining to be broadly interpreted to include metallurgy and petroleum. Eugene Holman, chairman of the Rand Metal Committee, is with Standard Oil Co. (N.J.), 30 Rockefeller Plaza, New York 20, N. Y.

Mathewson Medal for the Institute of Metals Div., paper which represents the most notable contribution to metallurgical science in the three-year period preceding the award. C. E. Nelson, chairman of the Mathewson Medal Committee, Dow Chemical Co., Midland, Mich.

Robert H. Richards Award to recognize achievement in any form which unmistakably furthers the art of mineral beneficiation in any of its branches. H. A. Pearse, chairman Richards Award Committee, Howe Sound Co., 730 Fifth Ave., New York, N. Y.

Robert W. Hunt Award for the best AIME paper on iron and steel. T. L. Joseph, chairman Hunt Award Committee, University of Minnesota, Minneapolis, Minn.

J. E. Johnson Jr. Award to a man under 40 who has exhibited exceptional ability in research, invention, or contributions to the technical literature related to the metallurgy or manufacture of pig iron. Paul R. Nichols, chairman Johnson Award Committee, Wisconsin Steel Works, South Chicago, Ill.

French Heads Connecticut Section

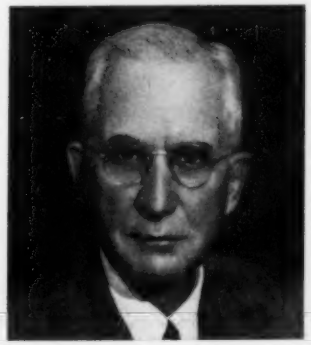
At the annual meeting of the Connecticut Section held April 13 in New Haven, Roland S. French, Bridgeport Brass Co., was elected Chairman for the 1951-1952 term. Other officers elected were: Franklin H. Wilson, American Brass Co., vice-chairman; William E. Milligan, Yale University, secretary-treasurer; Albert I. Blank, Chase Brass and Copper Co., chairman of publicity and attendance committees; Maur J. Weldon, Henry G. Thompson and Son Co., chairman of membership committee; and George F. Donahue, Handy and Harman, director-at-large.

Annual Meeting Paper Deadline

Sept. 15, 1951 is the deadline for all Institute of Metals Division papers for the 1952 New York Annual Meeting and the deadline for all Iron and Steel Division and Extractive Metallurgy Division papers to be prepublished.

Personals

ARTHUR W. THORNTON



LEWIS A. PARSONS

JAMES TUCKER MACKENZIE

Arthur W. Thornton has been appointed division superintendent, pipe production, finishing and shipping, at the National works of U. S. Steel's National Tube Co. He formerly held the position of division superintendent in charge of blast furnaces, open hearths, Bessemer convertors, and rolling mills.

Lewis A. Parsons, assistant consulting engineer for Calaveras Cement Co., San Francisco, has been elected 1951 president of the Engineers' Club of San Francisco.

William B. Distler is now associated with the Hall-Scott Div. of A.C.F., Brill Motors Co., Berkeley, Calif.

John D. Grimsley has become junior engineer for the National Bureau of Standards, Washington, D. C.

Calvin W. Clayton is vice-president, Clayton Securities Corp., Boston.

Charles H. Gorski has joined the pigments dept., E. I. duPont deNemours & Co., Inc., Newport, Del., and will be engaged in research on metallic titanium.

Harmon E. Keyes, chemical and metallurgical engineer, is now engaged with Infilco, Inc., Tucson. His developments in commercial application of the autoxidation process, formerly intended for leaching copper ores, have been expanded into the field of sanitation. Infilco, Inc. has taken over his patented process improvements for adaptation into the various industrial fields, including hydrometallurgy.

Everette L. De Golyer, senior partner, De Golyer & MacNaughton, Dallas and **Frederick Seitz,** research professor of physics at the University of Illinois, Urbana have been elected to membership in the National Academy of Sciences.

Gilbert R. Richardson is now with the National Carbon Co. (India) Ltd., Calcutta. He was previously located at Sydney, N.S.W., Australia for the Eveready Pty. Ltd.

C. W. Potter is assistant general manager, Bethlehem Steel Co., Steelton, Pa. He was formerly engineer of tests. **John B. Gero** has joined the research dept. of Bethlehem Steel Co., Bethlehem, Pa.

Carson L. Brooks, Aluminum Co. of America, Cleveland, is now at the Aluminum Research Laboratories, New Kensington, Pa.

R. E. Bromley is with the M. E. Solomon Co., Pittsburgh. He had been representative for the Samuel G. Keywell Co., Pittsburgh.

W. E. Dempster is now employed by the Aluminum Co. of Canada, technical dept., Arvida, Quebec.

James Tucker MacKenzie has been awarded the Herty Medal by the Georgia Section of the American Chemical Society, for outstanding contributions to chemistry in the Southeast. Dr. MacKenzie is technical director of the American Cast Iron Pipe Co., Birmingham, and was selected for his achievements in metallurgical research.

Otto Barth of the Royal Institute of Technology, Stockholm was in Turkey to start the new smelter of the Murgul Bakir Isletmesi (Murgul copper works) controlled by Etibank, Ankara.

Clarence H. Lorig, assistant director, Battelle Memorial Institute, Columbus has received a distinguished service citation for accomplishments in the field of metallurgical engineering, from the University of Wisconsin.

Arthur E. Schnaufer has been named general machinery division sales representative for the Duluth office of Allis-Chalmers Mfg. Co.

Orson A. Rockwell, general manager of the Calumet div., Calumet & Hecla Consolidated Copper Co. has been elected a vice-president.

Russell M. Bennett, Minneapolis and **Robert H. Cromwell,** Knoxville, both associated with the Electro Manganese Corp., were recently in Chile.

R. C. Fish, general manager of iron ore operations, M. A. Hanna Co., has been transferred from Duluth to Cleveland. **D. N. Vedensky** has been appointed director of research and development and **Morris Bradley** has been named director of public relations.

Amos J. Shaler has been promoted to associate professor, dept. of metallurgy at Massachusetts Institute of Technology.

Ray D. Dwyer has been named assistant to the general superintendent at U. S. Steel Co.'s Gary Works. He had been assistant division superintendent of open hearth operations.

Russell G. Hardy is now associated with American Steel Foundries, Indiana Harbor, Ind.

E. J. Duggan is executive vice-president for the Climax Uranium Co., Grand Junction, Colo.

Raymond A. Humphreys is now chief inspector for the Kellett Aircraft Co., Camden, N. J.

B. W. Carr is now technical representative for E. I. duPont deNemours & Co., Inc., New York. He was transferred from the Joplin, Mo. office.

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—Coming Events—

June 4, AIME, Mexico Section, American Club, Mexico City, Mexico.

June 11-15, ASME, semi-annual meeting, Royal York, Toronto, Canada.

June 11-15, Conference on Industrial Research, Columbia University, New York.

June 11-16, Armour Research Foundation of Illinois Institute of Technology. June 11-13, symposium on analysis and metallography of titanium. June 14-16, symposium on surfaces. Sheraton Hotel, Chicago.

June 15-16, AIME, Central Appalachian Section, Cumberland Hotel, Middleboro, Ky.

June 18-20, American Congress on Surveying and Mapping, annual meeting, Hotel Shoreham, Washington, D. C.

June 18-22, ASTM, annual meeting, Atlantic City, N. J.

June 23, AIME, Colorado Section and Subsections, Ouray, Colo.

July 30-Aug. 2, American Electroplaters' Society, Statler Hotel, Buffalo, N. Y.

Aug. 27-Sept. 6, Oak Ridge National Laboratory and Oak Ridge Institute of Nuclear Studies, annual summer symposium, Oak Ridge, Tenn.

Sept. 13-15, AIME, Industrial Minerals Div., fall meeting, University of West Virginia, Morgantown, W. Va.

Sept. 16-19, American Institute of Chemical Engineers, regional meeting, Sheraton Hotel, Rochester, N. Y.

Sept. 25-28, ASME, fall meeting, Radisson Hotel, Minneapolis.

Oct. 1-4, Assn. of Iron & Steel Engineers, annual convention, Hotel Sherman, Chicago.

Oct. 3-5, AIME, petroleum branch, fall meeting, Oklahoma City.

Oct. 9-12, Scientific Apparatus Makers Assn., mid-year meeting, Recorder-Controller Section, Seaview Country Club, Absecon, N. J.

Oct. 10-11, Joint Fuels Conference, AIME Coal Division, ASME Fuel Section, Roanoke Hotel, Roanoke, Va.

Oct. 15-17, AIME, Institute of Metals Div., fall meeting, Detroit-Leland Hotel, Detroit.

Oct. 15-19, National Metal Congress & Exposition, Detroit.

Oct. 19-20, Engineers' Council for Professional Development, annual meeting, Hotel Statler, Boston.

Oct. 22-24, American Mining Congress, Metal and Nonmetallic Mining Convention, Biltmore Hotel, Los Angeles.

Oct. 25-26, AIME, Los Angeles Section, fall meeting, Los Angeles.

Oct. 26-27, AIME, National Openhearth Committee, Southern Ohio Section, Deshler-Wallick Hotel, Columbus, Ohio.

Oct. 29-Nov. 3, AIME, fall meeting, Mexico City.

Nov. 2, AIME, Pittsburgh Section, annual off-the-record meeting, William Penn Hotel, Pittsburgh.

Nov. 25-30, ASME, annual meeting, Chalfonte-Haddon Hall, Atlantic City.

Nov. 28-30, Scientific Apparatus Makers Assn., midyear meeting, industrial instrument, laboratory apparatus, laboratory equipment, optical, nautical, aeronautical, and military instrument sections, Hotel New Yorker, New York.

Dec. 2-5, American Institute of Chemical Engineers, annual meeting, Chalfonte-Haddon Hall, Atlantic City.

Dec. 6-8, AIME, Electric Furnace Conference, William Penn Hotel, Pittsburgh.

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Proposed for Membership

Metals Branch AIME

Total AIME membership on Apr. 30 was 17,297; in addition 2303 Student Associates were enrolled.

ADMISSIONS COMMITTEE

Thomas G. Moore, Chairman; Carroll A. Garner, Vice-Chairman; George B. Corless, F. W. Hanson, Albert J. Phillips, Lloyd C. Gibson, R. D. Mollison, John T. Sherman. Alternates: A. C. Brinker, H. W. Hitzrot, Plato Malozemoff, Ivan Given, T. D. Jones, and W. H. Farrand.

Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by mail. The Institute desires to extend its privileges to every person to whom it can be of service but does not desire to admit persons unless they are qualified. Objections must be received before the 30th of the month on Metals and Mining Branches.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; AM, Associate Member; S, Student Associate.

California
San Francisco—Helmke, R. F. (M)
Selby—Platt, Robert R. (M)
Whittier—Wissmann, Conrad C. (M)

Connecticut
Waterbury—Korhonen, Aarre E. (M)

Delaware
Newport—Barth, Walter John (A)

District of Columbia
Washington—Raring, Richard (M)

Illinois
Chicago—Anthonisen, Robert P. (A). Della-Rose, Fred S. (J). Fisher, Edward S. (J) (R. C/S—S-J). MacKenzie, Archie R. (M)
La Grange—Parks, John M. (M) (C/S—J-M)

New Jersey
Newark—Meyer, Herbert M. (M)
Union—Weismantel, Elmer E. (J) (R. C/S—S-J)

New York
Brooklyn—Criswell, Wilbur W., Jr. (M) R.
Hamburg—Koegler, Harry A. (A). Winkler, Theodore B. (M) (C/S—J-M)
New York—Whitney, David W. (M) (C/S—J-M)
Troy—Nippes, Ernest F. (M)

Ohio
Bay Village—Nelson, John M. (M)
Campbell—Hornak, John A. (J)
Canton—Blough, Arthur K. (M) (R. C/S—A-M)
Cleveland—Eaton, James C. (J)
Euclid—Vitcha, Edward T. (A) (C/S—J-A)

Pennsylvania
Johnstown—Baer, Gordon R. (M). MacDonnell, Wilfred D. (M)
Latrobe—Neely, Grant F. (A)
McKeesport—McKee, Edward M. (M)
Monongahela—Sullivan, John G. (M)
Philadelphia—Dunkerley, Frederick J. (M) (C/S—A-M)
Pittsburgh—Bickell, Albert E. (A). Lovgren, Carl A. (A). Ogan, Albert C. (M). Patterson, Karl M. (A). Sigovich, Marion N. (A). Squier, William R. (J) (R. C/S—S-J)

Utah
Salt Lake City—Burt, Glen A. (M)

Washington
Seattle—Marquette, William H. (M)
Spokane—Peterson, Warren S. (M)
Tacoma—Harvey, Warren M. (A). Teats, Merrill C. (M) (C/S—J-M)

Australia
Melbourne—Russell, Reuben S. (M)

Belgium
Hoboken—Demerre, Mercel A. (M)

Canada
Montreal, P.Q.—Malabre, L. C. (J). Sansom, William (J)
Ontario—Carter, Ralph E. (J) (R. C/S—S-J)

England
London—Bakarian, P. W. (M) (R. C/S—J-M)

France
Mont-Saint-Martin—Laravoire, Louis (M)

Germany
Aachen, Veltmannplatz 4—Hilgers, Willy (A)

Japan
Akita-ken—Tsunoda, Suketoshi (M)

Netherlands
Zeist—Reysenbach, Johannes (J) (C/S—S-J)

Obituaries

NECROLOGY

Date Elected	Name	Date of Death
1916	U. H. Berthier	Mar. 1, 1951
1897	William McC. Cameron	Unknown
1945	Philip L. Edwards	Mar. 17, 1951
1935	Charles Engelhard	Dec. 1950
1907	G. T. Griswold	Mar. 22, 1951
1922	L. C. Harrington	Feb. 3, 1951
1935	J. S. Hemphill	Apr. 2, 1951
1896	John Kennedy	Unknown
1910	Jules Labarthe	Apr. 6, 1951
1944	B. E. Moir	Feb. 7, 1951
1921	Robert H. Ogburn	Mar. 1, 1951
1907	Brent N. Rickard	Mar. 8, 1951
1949	Thomas C. Russell	Mar. 13, 1951
1920	Dwight L. Sawyer	Feb. 16, 1951
1940	John H. Watrous	Nov. 27, 1950
1940	George Wilson	Nov. 25, 1950

Appreciation of Brent N. Rickard

By Howland Bancroft

Brent Neville Rickard, metallurgist, AIME Member 1907, Director 1934–1940, retired operating executive of the American Smelting & Refining Co., died on Mar. 8, 1951 in Tucson, Ariz. of cancer of the lungs. Brent was born in Anaconda, Mont. on June 28, 1885 of English-Irish parents, Stephen and Constance Neville Rickard, early friends of a gentleman from Sweden who came to America in his early manhood and who later became the foremost mining geologist of his time, Waldemar Lindgren. Brent's maternal grandmother, Mrs. Neville, arrived in San Francisco in 1856 and lived there throughout its growth from that time until 1904 when she joined Brent's parents in residence in Denver. The California Historical Society, through the thoughtful courtesy of Brent, is now the possessor of some 40 large scrap books and 12 albums in which Mrs. Neville recorded interesting events in that colorful era of San Francisco's history.

During Brent's early childhood his parents moved from Anaconda to Denver where young Brent, during the time he was attending public schools in Denver, also learned assaying from his father, a chemist and assayer of repute. Brent was thus equipped to earn a living while still a student in the Denver Manual Training High School and he put his knowledge and skill in assaying to early use by leaving college in order to assist in financing the collegiate education of his two brothers. While his formal education was thus limited to one year in the University of Michigan his practical technical education through experience was continuous from the time he first bucked a sample for his Dad until he retired after 40 years of continuous service with the American Smelting & Refining Co. during which time he rose from chemist to metallurgist to assistant superintendent to superintendent to assistant manager and finally to manager of different units of the smelting branch of that corporation.

Brent's adult life was spent in Mexico and in the Western part of the United States. A chronological summary of his professional career is to be found in *Who's Who in Engineering* as well as in *Who's Who in America* where details regarding his various assignments along with corresponding dates are available. However, these publications quite naturally make no

BRENT N. RICKARD

mention of his personal characteristics and it is the purpose of this brief appreciation to bring some of these to the attention of those not fortunate enough to have had personal contact with a man who spent his life doing things for others. All who really knew Brent were fully aware of the continuity of his service to mankind.

Brent was the prospectors' and small mine operators' friend and confidant. None of their problems was too small for his serious and considerate attention. He thought of public service as a duty to be cheerfully performed and his participation in many public activities endeared him to the hearts of youngsters and earned him the appreciation and gratitude of his fellow citizens. He took a very active part in the affairs of the American Institute of Mining and Metallurgical Engineers and of the American Mining Congress in whatever part of the United States he happened to have headquarters, and these organizations benefitted greatly from his association.

During World War II Brent was "loaned" to Metals Reserve Co. from time to time to assist in some of their activities and his help was greatly appreciated by those with whom he came in contact.

Brent was a truly remarkable husband, a wonderful and thoroughly appreciated father and he had the good fortune to witness the early years of five grandchildren. In the words of one of the many young people he helped along the way Brent was truly "an honorable man." The world is better off for his having lived in it.

William Mc. Cameron (Member 1897), formerly associated with the Celanese Corp. of America, has died. He graduated from Michigan College of Mines, and was associated with Union Leasing and Mining Co., Leadville, Colo; Small Holes Consolidated Mining Co.; and American Cellulose & Chemical Mfg. Co., Ltd., New York.

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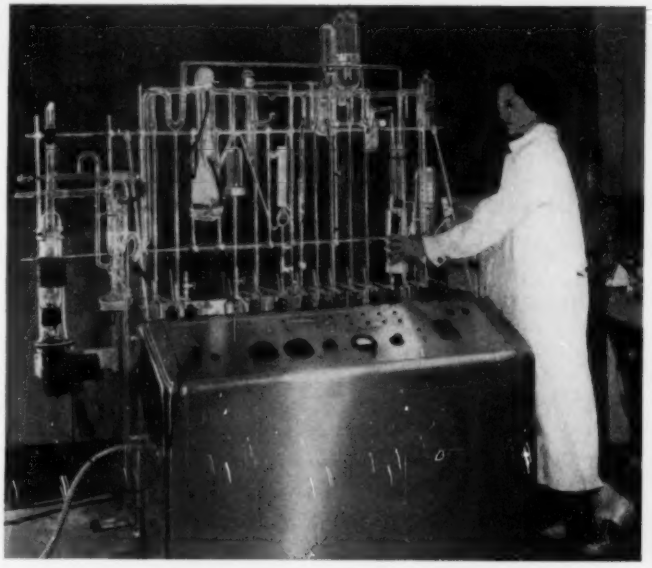

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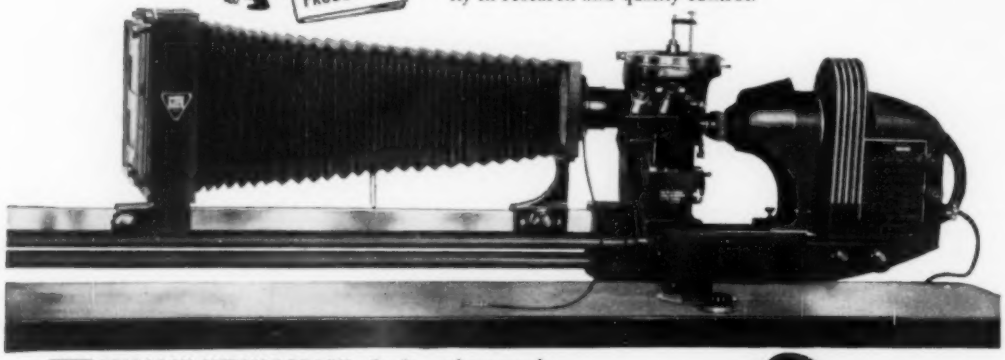

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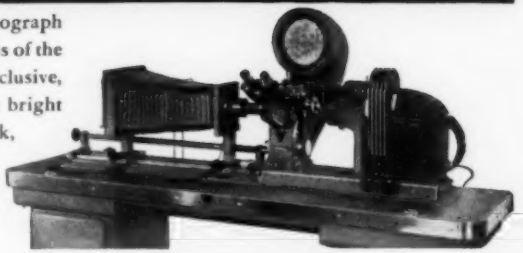

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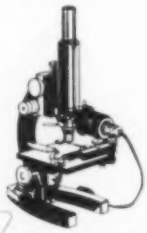

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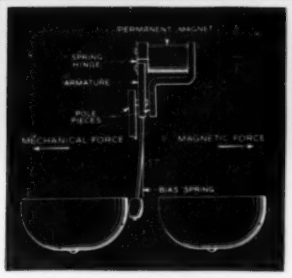

The Bell System's new automatic method of adjusting telephone ringers uses a beam of light passing between the gongs to a photoelectric cell. When test currents are applied to the ringer the machine decides whether to change the spring tension or the magnetic pull. After each change it tests again until the ringer is in perfect adjustment—and the whole procedure takes only 30 seconds.

To YOU, it's your familiar telephone bell. To telephone engineers, it's a "ringer." And it has two jobs to do. It must ring, of course, when someone calls you. And it must overlook the numerous electrical impulses which do not concern it, such as those sent out by your dial.

Ability to respond to some impulses, to ignore others, requires exact adjustment between the pull of a magnet and the tension of a spring. If they are out of balance your telephone might tinkle when it oughtn't, or keep silent when it should ring.

In the past, adjustment was made by hand, little by little until the proper setting was reached. It took time. But now Bell Laboratories engineers have developed a machine which adjusts new ringers perfectly, before they leave the Western Electric Company plants where they are made. And the operation takes just 30 seconds.

This is another example of how the Laboratories work constantly to improve every phase of telephony —keeping the costs low while the quality of service grows higher and higher.

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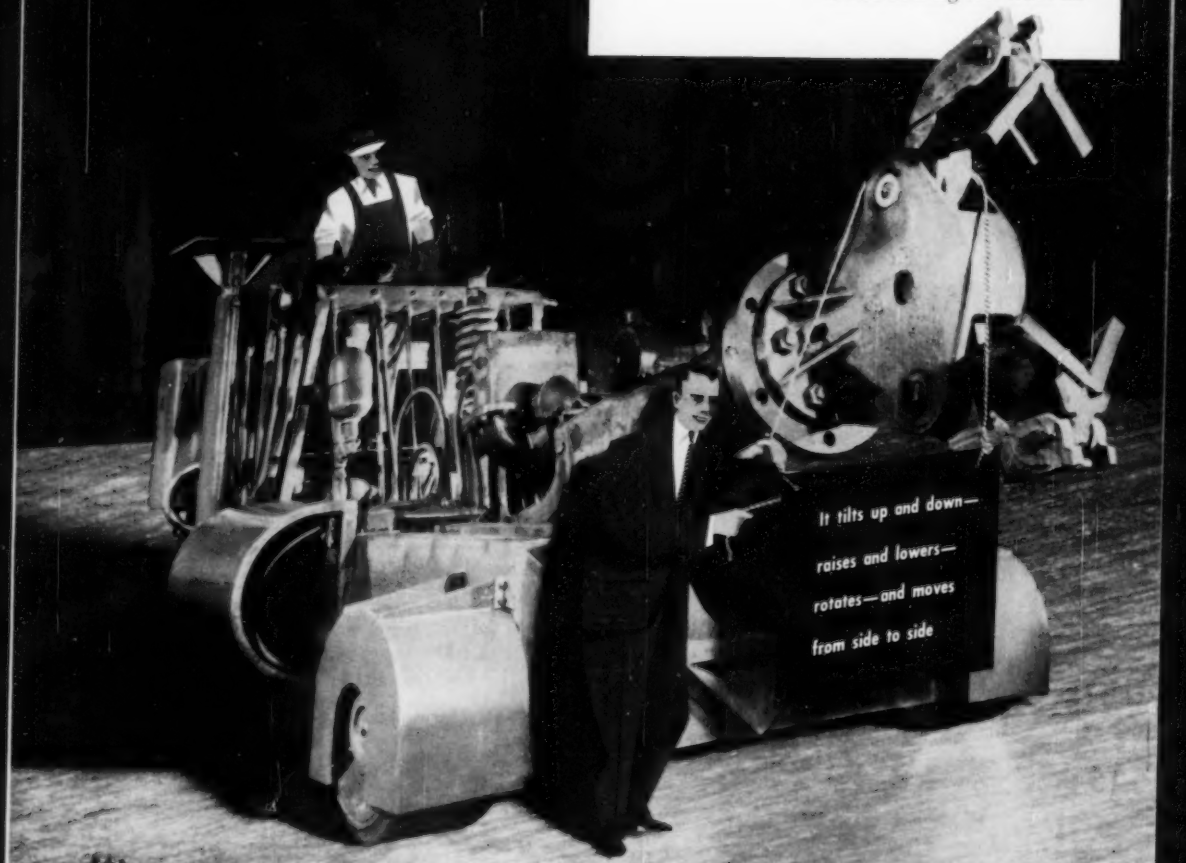

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Holds meetings first Friday of each month except July and August

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J. C. Kieffer, *Secretary-Treasurer*
Spokane-Idaho Mining Co.
Box 930, Kellogg, Idaho

Lewis A. Grant, *Section Delegate*

SPOKANE SECTION

W. W. Staley, *Vice-Chairman*
Harold Kirkemo, *Assistant Secretary*

SNAKE RIVER SUBSECTION

Edward B. Douglas, *Vice-Chairman*
Harry W. Marsh, *Assistant Secretary*

CONNECTICUT

Established September 30, 1947

Holds meetings second Wednesday, October, December, February and April

R. S. French, *Chairman*
F. H. Wilson, *Vice-Chairman*
William E. Milligan, *Secretary-Treasurer*
Yale University, New Haven, Connecticut

Lewis E. Thelin, *Section Delegate*

COMMITTEE CHAIRMEN

Albert I. Blank, *Publicity and Attendance*
Maur J. Weldon *Membership*

George F. Donahue, *Director-at-Large*

DELTA

Established September 18, 1946

Meets second Tuesday in the month except during June, July, and August

H. M. Krause, Jr., *Chairman*
Raymond B. Kelly, Jr., *Vice-Chairman*
Charles A. Capps, *Vice-Chairman*
J. F. Homer, *Secretary*
Humble Oil & Refining Company
1405 Canal Bldg.
New Orleans, Louisiana

A. L. Vitter, *Treasurer*
H. O. Loehr, *Journal Secretary*
H. M. Krause, Jr., *Section Delegate*

DIRECTORS

E. N. Van Dusee
Murray Hawkins
J. H. Rambin
Fred E. Simmons, Jr.

COMMITTEE CHAIRMEN

John M. Dillon, Jr., *Activities*
H. C. Loehr, *Publicity*
J. A. Battle, Jr., *Program*
C. A. Capps, *Membership*
L. A. J. Monroe, *House*

MISSISSIPPI SUBSECTION

J. K. Wright, Jr., *Chairman*
T. H. Jackson, Jr., *First Vice-Chairman*
S. J. Poythress, Jr., *Second Vice-Chairman*
Eugene J. Burnet, *Secretary-Treasurer*
Mississippi Oil and Gas Board
P. O. Box 347, Jackson, Mississippi

Board of Directors

J. O. Crose
R. F. Moore

DETROIT

Established February 18, 1936

Holds meetings third Monday of each month except June through September

F. Bens, *Chairman*
H. Moser, *Vice-Chairman*
E. Engle, *Secretary*
Carboloy Co., Inc.
Detroit, Michigan

B. Beckwith, *Treasurer*

R. D. Chapman, *Section Delegate*

EXECUTIVE COMMITTEE

H. Anderson
F. Bens
E. Dofter
C. Gorton
N. Lazar
M. Semchyshen
D. Frey

H. Anderson, *Chairman, Membership*

EAST TEXAS

Established April 18, 1940

Holds meetings the second Tuesday of each month except July through September

W. W. Leonard, *Chairman*
W. B. Mays, *Vice-Chairman*
W. E. LaRoche, *Secretary-Treasurer*
Tide Water Associated Oil Company
Drawer 152, Kilgore, Texas

W. W. Leonard, *Section Delegate*

DIRECTORS

Bert Crowder
P. J. Lehnhard
H. L. Long
W. S. Morris
P. E. DesJardins
B. F. Patterson, Jr.
R. K. Thies
J. A. Walker

EL PASO METALS

Established March 25, 1927

Holds meetings second Wednesday of each month

A. F. Horle, *Chairman*
C. S. Harper, Jr., *Vice-Chairman*
Guy E. Ingersoll, *Secretary-Treasurer*
Texas Western College
912 W. Yandell Blvd.
El Paso, Texas

Eugene M. Thomas, *Section Delegate*

DIRECTORS

M. S. Darbyshire — W. P. Hewitt
E. W. Donahue — W. S. Strain
M. W. Hayward — A. J. Thompson
R. L. Hennebach

COMMITTEE CHAIRMEN

O. Paul Lance, *Membership*
Hardy F. Kennady, Jack H. Nelson, *Meeting Arrangements*

Programs
March - J. F. Graham
April - R. C. Wilson
May - R. G. Ponsford, Jr.
Sept. - P. A. Alers
Oct. - E. M. Thomas
Nov. - R. J. Benson
Dec. - B. B. Kunkle
Jan. - R. J. Mellen

J. E. Despins, *Reception*

FLORIDA

Established September 27, 1949

Holds meetings the first Monday of each month

James B. Cathcart, *Chairman*
John W. Pamplin, *Vice-Chairman*
Robert Thomas, *Secretary-Treasurer*
P. O. Box 831, Plant City, Florida

Allen T. Cole, *Section Delegate*

STEERING COMMITTEE

James B. Cathcart, *Chairman*
E. T. Casler — Robert Thomas
Allen T. Cole — J. L. Weaver
N. Morris Faulds — O. H. Wright
John W. Pamplin

COMMITTEE CHAIRMEN

N. Morris Faulds, *Membership*
O. H. Wright, *Program*

GULF COAST

Established December 13, 1935

Holds meetings the third Tuesday of each month

Alfred W. Waddill, *Chairman*
George R. Gray, *Vice-Chairman*
George H. Fancher, *Vice-Chairman*
Albert B. Stevens, *Vice-Chairman*
Everett F. Stratton, *Secretary-Treasurer*
1720 Niels Esperson Bldg.
Houston 2, Texas

Julian E. Kastrop, *Section Delegate*

DIRECTORS

T. C. Borland — H. A. Otto
Julian Kastrop — E. L. Petree
E. B. Miller, Jr. — E. A. Rassinier

COMMITTEE CHAIRMEN

Fred S. Reynolds, *House*
J. S. Levine, *Activity*
W. B. Hopkins, *Membership*
K. B. Ford, *Program*
C. Leon Singleton, *Journal Editor*

KANSAS

Established November 17, 1948

Meets third Wednesday of each month except June through August

G. L. Yates, *Chairman*
J. C. Gallivan, *Vice-Chairman*
T. J. Hamilton, *Vice-Chairman*
L. W. Holsapple, *Vice-Chairman*
George J. Decker, *Secretary-Treasurer*
Schlumberger Well Survey Corp.
Box 1034, Wichita, Kansas

G. L. Yates, *Section Delegate*
J.R. Berg, *Director* — E.L. Anders, *Director*

LEHIGH VALLEY

Established March 27, 1924

B. L. Larpenteur, *Chairman*
R. B. Hoy, *Vice Chairman*
H. R. Gault, *Vice Chairman*
J. S. Marsh, *Vice Chairman*
A. F. Peterson, Jr., *Secretary*
Bethlehem Steel Co.
Bethlehem, Pennsylvania

R. G. Peets, *Treasurer*
R. T. Gallagher, *Section Delegate*

MANAGERS

M. L. Fuller R. T. Gallagher
P. W. Ramsey

COMMITTEE CHAIRMEN

R. B. Hoy & W. S. Cumings, *Program*
D. S. Lyons, *Membership*
E. B. Mancke & C. G. Tebelman, *Hospitality*
E. A. Anderson, *Student Affairs*
M. L. Fuller, *Nominations*

MID-CONTINENT

Established December 28, 1917

Holds weekly luncheon meetings each Thursday in Tulsa, Oklahoma. Regular Section Meetings held second Monday each month except June through August.

James N. McGirl, *Chairman*
Jack H. Beesley, *First Vice-Chairman (Programs)*
G. C. MacDonald, *Second Vice-Chairman (Membership)*
John H. Jennings, *Secretary-Treasurer*
Ohio Oil Company
Thompson Bldg., Tulsa, Oklahoma
Roy H. Smith, *Section Delegate*

EXECUTIVE COMMITTEE

(Tulsa)

C. H. Danchertsen M. B. Penn
A. E. Smith

Past Chairmen, ex officiis

H. M. Cooley Roy H. Smith

(Outside Tulsa)

Harold S. Kelly E. S. Messer

MINNESOTA

Established December 20, 1920

Annual meeting second week in January other meetings as called by officers

Grover J. Holt, *Chairman*
Hugh Leach, *Vice-Chairman*
W. N. Matheson, *Vice-Chairman*
E. P. Pfleider, *Vice-Chairman*
D. M. Davidson, *Secretary-Treasurer*
E. J. Longyear Company
1701 Foshay Tower
Minneapolis 2, Minnesota
Eugene P. Pfleider, *Section Delegate*

Directors

E. P. Scallon W. L. Taylor
C. J. O'Connell

MONTANA

Established October 17, 1913

Holds meetings the fourth Tuesday of each month

Kuno Doerr, Jr., *Chairman*
C. H. Steele, *Vice-Chairman*
F. W. Strandberg, *Secretary-Treasurer*
Anaconda Copper Mining Company
421 Hennessy Bldg., Butte, Montana
F. W. Strandberg, *Section Delegate*

EXECUTIVE COMMITTEE

R. H. Miller M. C. Mesmer

COMMITTEE CHAIRMEN

William Waylett, *Membership*
J. T. Roy, *Program*
Clarence Champ, *Student Awards*
A. B. Martin, *Nominating*

Chairman Advisors on Current and Desirable Subjects for Meetings

E. S. McGlone, *Mining*
M. H. Gidel, *Geology*
R. B. Caples, *Metallurgy*
A. E. Adam, *General*

NEVADA

Established January 21, 1916

Albin C. Johnson, *Chairman*
Albert Silver, *Vice-Chairman*
Andrew C. Rice, *Secretary-Treasurer*
U. S. Bureau of Mines
Box D, University Station
Reno, Nevada
J. C. Kinnear, Jr., *Section Delegate*

EXECUTIVE COMMITTEE

T. A. Copeland John Heizer
R. A. Hardy J. C. Kinnear, Jr.

RENO BRANCH

Luncheon meeting the first Thursday of each month

Clyde Collins, *Chairman*
Parker Lidell, *Secretary-Treasurer*
1500 Watt St., Reno, Nevada

NEW YORK

Established May 19, 1911

Holds monthly meetings except February, June, July, and August

Francis Cameron, *Chairman*
Philip D. Wilson, *Past Chairman*
L. C. Raymond, *Vice-Chairman*
P. Malozemoff, *Vice-Chairman*
James S. Vanick, *Treasurer*
R. H. W. Chadwick, *Secretary*
Metal Co., Ltd.
61 Broadway, New York 6, N. Y.
Philip D. Wilson, *Section Delegate*

COMMITTEEMEN

Ira K. Hearn
H. W. Hitzrot
Alvin Knoerr
Domingo Moreno
R. H. Ramsey
E. H. Thaete, Jr.

NORTH PACIFIC

Established March 28, 1913

Holds meetings third Thursday of each month except June, July and August

W. C. Leonard, *Chairman*
Drury A. Pifer, *Vice-Chairman*
A. H. Mellish, *Secretary-Treasurer*
American Smelting & Refining Company
P.O. Box 1605, Tacoma 1, Washington
M. E. Elmore, *Corresponding Secretary*
W. C. Leonard, *Section Delegate*

COUNCILLORS

Milnor Roberts
F. J. Dohrer
L. W. Heinzinger

COMMITTEE CHAIRMEN

C. H. Randt, *Membership*
H. G. Poole, *Program*

REPRESENTATIVES TO P. S. E. COUNCIL

F. J. Dohrer
Milnor Roberts

NORTH TEXAS

Established May 16, 1945

Jack A. Crichton, *Chairman*
K. Marshall Fagin, *Vice-Chairman*
Gus Athanas, *Vice-Chairman*
Earl C. Taylor, Jr., *Vice-Chairman*
Kenneth F. Anderson, *Secretary-Treasurer*
Bureau of Mines, Dallas, Texas
Jack A. Crichton, *Section Delegate*

DIRECTORS

Joab B. Harrell, Jr.
R. G. Parker
Pat Reardon
W. E. Stiles
Gordon R. Stine

OHIO VALLEY

Established November 19, 1920

John H. Melvin, *Chairman*
Richard J. Lund, *Vice-Chairman*
William H. Smith, *Secretary-Treasurer*
Ohio Division of Geology Survey
Orton Hall, Ohio State University
Columbus, Ohio
W. A. Mueller, *Section Delegate*

COMMITTEE CHAIRMEN

James W. Cunningham, *Program*
William H. Newton, *Membership*
Arthur Westerman, *Member Representative*

AREA REPRESENTATIVES

B. M. O'Harra, *Cincinnati*
George R. Long, *Dayton*
G. W. Noble, *Findlay*
Max A. Tuttle, *Indianapolis*
Cecil E. Bales, *Ironton*
Harold P. Gaw, *Middletown*
Theron W. Reed, *Newark*
Benjamin Eggers, *Portsmouth*
James D. Reilley, *St. Clairsville*

OKLAHOMA CITY

Established February 18, 1947

J. H. Field, *Chairman*
J. C. Cordell, *First Vice-Chairman*
R. M. Caywood, *Second Vice-Chairman*
M. J. Popovich, *Secretary-Treasurer*
Sohio Petroleum Company
Skirvin Tower, Oklahoma City, Oklahoma

J. H. Field, *Section Delegate*

DIRECTORS

Henry Waszkowski — J. W. Maly
Edward Saye, III

OREGON

Established April 22, 1921

Holds meetings third Friday of each month except during summer months

David H. Beetem, *Chairman*
Stephen M. Shelton, *Vice-Chairman*
Albert O. Bartell, *Past Chairman*
James Forbes Bell, *Secretary*
Portland Gas & Coke Company
Public Service Bldg.
Portland 4, Oregon

D. H. Beetem, *Section Delegate*

EXECUTIVE COMMITTEE

A. O. Bartell — J. McWilliams
D. H. Beetem — Ernest Messer
J. F. Bell — S. M. Shelton

L. H. Banning, *Membership Chairman*

PENNSYLVANIA-ANTHRACITE

Established February 17, 1914

Holds meetings alternately at Pottsville, Hazleton, Wilkes-Barre and Scranton. Spring meeting, April; Summer meeting, July; Fall meeting, October.

Henry A. Dierks, *Chairman*
D. C. Helms, *Vice-Chairman*
Floyd S. Sanders, *Secretary-Treasurer*
Goodman Manufacturing Company
35 New Bennett Street
Wilkes-Barre, Pennsylvania

Cadwallader Evans, Jr., *Section Delegate*

EXECUTIVE COMMITTEE

John W. Buch — Earl W. Lamb
George J. Clark — William C. Muehlof
E. L. Dana — W. Julian Parton
William W. Everett — Walter B. Petzold
Edward G. Fox — James H. Pierce
Carroll A. Garner — Edward T. Powell
J. M. Humphrey, Jr. — John M. Reid
Wilmot Jones — George A. Roos, ex officio

J. T. Griffiths, *Membership Chairman*

PERMIAN BASIN

Established November 14, 1945

Jack M. Moore, *Chairman*
Joe Chastain, *Vice-Chairman*
Ray Ousterhaut, *Secretary-Treasurer*
Dowell, Inc.
409 W. 21 St.
Odessa, Texas

Jack M. Moore, *Section Delegate*

BOARD OF DIRECTORS

Bryan Denson — Ray Howard
W. N. Little

COMMITTEE CHAIRMEN

T. C. Frick, *Welcoming*
Ray Howard, *Program*
J. T. Lewis, *Membership*

SOUTH PLAINS SUBSECTION

R. W. Coburn, *Chairman*
J. B. Rosen, *First Vice-President*
John Gould, *Second Vice-President*
K. D. Snedeker, *Secretary-Treasurer*
Kobe Inc., Box 849,
Brownfield, Texas

PHILADELPHIA

Re-established March 15, 1944

Dinner and meeting held last Thursday each month except June through September

A. L. Jamieson, *Chairman*
D. Finch, *First Vice-Chairman*
A. A. Bradd, *Second Vice-Chairman*
F. J. Dankerley, *Secretary-Treasurer*
University of Pennsylvania
247 Engineering Bldg.
Philadelphia, Pennsylvania

A. L. Jamieson, *Section Delegate*

EXECUTIVE COMMITTEE

C. B. Allen — A. L. Jamieson
A. Bounds — F. B. Litton
A. W. Greavenor, *Ex officio*
F. Foley, *Ex officio*

PITTSBURGH

Established 1920

G. J. Donaldson, *Chairman*
R. F. Miller, *Vice-Chairman*
E. H. Hollingsworth, *Secretary*
Aluminum Research Laboratories
Aluminum Co. of America
New Kensington, Pennsylvania
R. D. Snouffer, *Treasurer*
Linwood Thiessen, *Section Delegate*

EXECUTIVE COMMITTEE

N. G. Alford — D. T. Rogers
H. G. Botset — D. W. Pettigrew, Jr.
A. J. Breitenstein — J. T. Ryan, Jr.
G. Derge — W. G. Stevenson
S. Feigenbaum — C. H. Sawyer
H. P. Greenwald — J. M. Stewart
M. G. Gulley — Linwood Thiessen
J. B. Morrow — W. L. Wearly
A. B. Wilder, *Ex Officiis*
H. N. Eavenson — L. E. Young

S. Feigenbaum, *Chairman*
Annual All-Day Off-the-Record Technical Session

ST. LOUIS

Established May 23, 1913

Norman Hinchey, *Chairman*
Curtis Wilson, *Vice-Chairman*
Nat L. Shepard, *Past-Chairman*
John D. Kerr, Jr., *Secretary-Treasurer*
St. Louis Chamber of Commerce
511 Locust Street
St. Louis, Missouri
Clyde S. Smith, *Section Delegate*

EXECUTIVE COMMITTEE

Howard I. Young — O. M. Bishop
Carl G. Stifel — Ernest L. Ohle
John E. Lamar — Clyde Smith

Howard E. Hutters, *Program Chairman*

SAN FRANCISCO

Established June 26, 1913

Holds meetings second Wednesday of each month except June through August; and Monday noons for luncheon at Engineers' Club

George H. Playter, *Chairman*
Walter L. Penick, *Vice-Chairman*
J. G. Huseby, *Secretary-Treasurer*
Room 700, 216 Pine Street
San Francisco 4, California
E. H. Wisser, *Section Delegate*

COMMITTEE CHAIRMEN

Walter L. Penick, *Program*
J. C. Lokken, *Membership*
Edward Wisser, *Student Contact*
Granville S. Borden, *Tax*
Bernard York, '52, *Student Prize*
Lawrence B. Wright, *Licensing*
Granville S. Borden, *Entertainment and Hospitality*
W. Spencer Reid, *Advisory*
A. A. Hoffman, *Finance*
H. A. Sawin, *Nominating*
Edward W. Bullard, *Advisory Committee of Eng. Society Employment Service*
Philip R. Bradley, Jr., *Legislative*
W. W. Mein, Jr., *Engineering Council*

SOUTHEAST

Established February 18, 1936

W. C. McKenzie, *Chairman*
E. H. Rose, *First Vice-Chairman*
Alfred Shook III, *Second Vice-Chairman*
Wayne L. Dowdey, *Secretary-Treasurer*
Eimco Corporation
3140 Fayette Ave., Birmingham, Alabama
W. C. Chase, *Section Delegate*

DIRECTORS

W. C. Chase — Hugh Kendall
P. G. Cowin — Nelson Severinghaus
Wm. Black — R. H. Hopkins

COMMITTEE CHAIRMEN

M. C. McCall, *Membership*
C. H. Dewey, *Program*
Monro B. Lanier, II, *Entertainment*
Howard Cobb, *Publicity*
J. W. Stewart, *Development of Jr. Engineers*
E. H. Stevens, *Student Counselor*
C. H. Dewey, *Representative Birmingham Engineers Council*

SOUTHERN CALIFORNIA

Established May 23, 1913

J. A. Kavenaugh, *Chairman*
P. A. Haythorne, *Secretary*
2521 Rinconia Ave.
Los Angeles 28, California

C. W. Six, *Treasurer*
J. A. Kavenaugh, *Section Delegate*

DIRECTORS

John Bizley, *Metals Branch*
Richard Stewart, *Mining Branch*
Basil Kantner, *Petroleum Branch*
Ian Campbell, *Past Chairman Mining Branch*

SOUTHWESTERN ALASKA

Established February 1951

SOUTHWEST TEXAS

Established September 18, 1946

Holds meetings second Wednesday of each month except July, August and December

Lee J. Thronson, *Chairman*
George Wilson, *Vice-Chairman*
Harry D. Vaughan, *Secretary-Treasurer*
Lone Wells Co., P. O. Box 389
Corpus Christi, Texas

Lee J. Thronson, *Section Delegate*

DIRECTORS

B. Booth	Henry Kerr
J. M. Clark	Carl Peters
R. C. Granberry, Jr.	Frank Saye
F. Hebert	D. F. Shaw
C. W. Kelley	Chester Wheless

COMMITTEE CHAIRMEN

C. L. Wheless, *Membership*
D. F. Shaw, *Program*

SAN ANTONIO-AUSTIN SUBSECTION

W. H. Spice, Jr., *Chairman*
H. H. Powers, *Vice-Chairman*
J. B. Jones, *Secretary-Treasurer*

DIRECTORS

Oscar Goode	W. E. Richards
J. H. McQuown	Harry Rosser

SOUTHWESTERN NEW MEXICO

Established September 30, 1947

Holds meetings second Wednesday in January, April, July and October

T. Alfred Snedden, *Chairman*
Jerry W. Faust, *First Vice-Chairman*
Robert M. Hernon, *Second Vice-Chairman*
David W. Boise, *Secretary-Treasurer*
917 West Street
Silver City, New Mexico

COMMITTEE CHAIRMEN

W. J. Akert, *Membership*
Elton Clark, *Program*

TRI-STATE

Established May 27, 1926

Ernest Blessing, *Chairman*
Joseph P. Lyden, *Vice-Chairman*
William F. Netzeband, *Secretary-Treasurer*
Box 870, Joplin, Missouri

Dan Stewart, *Section Delegate*

DIRECTORS

Ernest Blessing	H. A. Krueger
S. S. Clarke	Joseph P. Lyden
F. J. Caddeback	William F. Netzeband
George M. Fowler	Jacob C. Stroup

COMMITTEE CHAIRMEN

F. J. Caddeback, *Membership*
S. S. Clarke, *Program*

UPPER PENINSULA

Established October 25, 1918

A. J. Christenson, *Chairman*
Robert K. Pouil, *Vice-Chairman*
Roy W. Drier, *Secretary-Treasurer*
College of Mining & Technology
715 Pine St., Calumet, Michigan

P. P. Ribotto, *Section Delegate*
Roy W. Drier, *Alternate*

ADVISORY COMMITTEE

F. W. Denton, Jr.

COMMITTEE CHAIRMEN

A. J. Christenson, *Executive*
Carl Brewer, *Nominating*
Roy W. Drier, *Finance*
Roy W. Drier, *Program*
Fred W. Denton, *Membership*
A. K. Snelgrove, *Student Relations*
W. A. Knoll, *Entertainment*
Roy W. Drier, *Publicity*
F. E. Brown, *Professional Standards*

UTAH

Established April 24, 1914

Carlos Bardwell, *Chairman*
W. G. Rouillard, *Vice-Chairman*
Harry P. Allen, *Secretary-Treasurer*
1316 Penn Street
Salt Lake City,5, Utah

B. E. Grant, *Section Delegate*

EXECUTIVE COMMITTEE

C. J. Christensen — M. B. Kildale
J. M. Ehrhorn — H. L. Johnson

COMMITTEE CHAIRMEN

J. F. Dugan, *Membership*
Hurt B. Brewster, *Publicity*
Robert S. Lewis, *Student Affairs*
E. Kipp, *Entertainment*

WYOMING

Established May 18, 1930

Holds regular meetings quarterly; special meetings when speakers are available.

Frank J. Peternell, *Chairman*
H. G. Fisk, *Vice-Chairman*
Frank Kratka, *Secretary-Treasurer*
Union Pacific Railroad Company
Box 1072, Rock Springs, Wyoming

Frank J. Peternell, *Section Delegate*
I. N. Bayless, *Alternate*

EXECUTIVE COMMITTEE

I. N. Bayless — I. M. Charles
G. B. Pryde

MEMBERSHIP COMMITTEE

W. T. Nightingale, *Chairman*
V. O. Murray

WASHINGTON, D. C.

Established June 21, 1918

Holds meetings usually third Tuesday of each month except June through August

Paul M. Tyler, *Chairman*
H. B. McCormick, *Vice-President for D.C.*
Charles E. Stott, *Vice-President for Maryland*
Julian W. Feiss, *Vice-Chairman for Virginia*
J. W. Clark, *Secretary-Treasurer*
U. S. Bureau of Mines, Dept. of the Interior
Washington 25, D. C.

F. T. Moyer, *Section Delegate*

EXECUTIVE COMMITTEE

A. W. Dickenson — Henry C. Morris
R. L. Wilcox

FOREIGN SECTIONS

MEXICO

Established 1950

Holds monthly luncheon meetings first Monday of each month at American Club, Mexico City

Alfredo Terrazas, *Chairman*
Valentin Garfias, *Vice-Chairman*
William G. Kane, *Secretary-Treasurer*
P. O. Box 711, Mexico City, D.F.

PHILIPPINE

Established January 20, 1939

Nestorio N. Lim, *Chairman*
Ananias Crisostomo, *Secretary-Treasurer*
157-A Mayon St.
Quezon City, P.I.

RIO DE JANEIRO (Brazil)

Established April 17, 1936

Holds meetings Thursday of each month at Av. Rio Branco 128, Room 410

E. de Macedo Soares S., *Chairman*
A. I. de Oliveira, *Vice-Chairman*
Harvey Hakala, *Vice-Chairman*
Frank E. Noe, *Secretary*
Silvio Froes Abreu, *Secretary*
Instituto Nacional de Tecnologia
Rio de Janeiro, Brazil

H. C. Alves de Sousa, *Treasurer*

STUDENT CHAPTERS

1951

FACULTY SPONSORS

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MINING AND METALLURGICAL SOCIETY
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Guinn Metzger

UNIVERSITY OF ARIZONA
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UNIVERSITY OF BRITISH COLUMBIA
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UNIVERSITY OF CALIFORNIA
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THE METALS CLUB
Gerhard Derge

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